CRANFIELD UNIVERSITY

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The Rapid Design of Simulation Models Using Cladistics and Template Based Modelling

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ABSTRACT

The drive towards a more globally competitive market has led to an increase in demand for goods and services on a global scale. As a result of this increase in productivity, production systems are being designed and redesigned at an increased rate and that they are becoming more innovative as they progress with time.

The challenge this research attempts to address is how to improve the ability of the UK-based manufacturing industry to make a more effective decision during manufacturing systems design/redesign by adopting simulation techniques as both strategic and operational decision making tools. The aim of this research is to develop a classification scheme based on cladistics and evolutionary analysis and to use this classification in the development of a template based modelling library. The research focused on identifying the existing manufacturing layout types, the various layout configurations that are being used and template based model generation. Some of the major developments of the research conducted were the construction of the manufacturing layout and component based cladograms and the RapidSim generator.

A literature review on manufacturing systems layouts revealed the types of system layouts which are most commonly used in the manufacturing sector as well as the component configurations and characteristics which are found within each production systems. This research makes a major contribution by providing a cladistical classification of manufacturing systems layouts, an external interface for model building and development and a set of recommendations, which when adopted may help increase the use of template based simulation modelling. Based on the data analysis carried out, the findings suggest that there is room for the development and implementation of a template based modelling approach to the development of simulation based models. The most important result obtained from the validation of the model was that the time taken to build and run the model decreased significantly by around 65% when compared to the conventional model building process.

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GLOSSARY OF TERMS

RAPIDSIM	Rapid simulation modelling tool
CAD	Computer aided design
COTSS	Commercial off the shelf software
HLA	High level architecture
FSO	File system object
FMS	Flexible manufacturing system
RMS	Reconfigurable manufacturing system
CNC	Computer numerical control
DNC	Direct numerical control
TL	Transfer line
FTL	Flexible transfer line
AGV	Automated guided vehicle
OEM	Original equipment manufacturer
DPD	Delayed product differentiation
UPGMA	Un-weighted paired group method with mean arithmetic
WIP	Work in progress
RSM	Reusable simulation model
VBS	Visual basic scripting
WCL	Witness command language
VBA	Visual basic for application
NPARTS	Number of parts
M&S	Modelling and Simulation

PUBLICATIONS

Conference Papers:

Rampersad, K., Tjahjono, B., 2010. Rapid Simulation Modelling Using Cladistics: *Proceedings of the 8th International Conference on Manufacturing Research ICMR 2010.*

Rampersad, K., Tjahjono, B., 2008. An Initial Classification and Compilation of Manufacturing Systems. *Proceedings of the Cranfield Multi-Strand Conference: 6-7 May 2008*

Chapter 1

Introduction

1 INTRODUCTION

The drive towards a more globally competitive market has led to an increase in demand for goods and services on a global scale. As a result of this increase in productivity, production systems are being designed and redesigned at an increased rate and that they are becoming more innovative as they progress with time. To describe any given production system there needs to be an outline of both the organisational and technological variables which determine the manufacturing systems level of functionality. These can be summed up by four basic variables which help make up any production system; they being the degree of specialization; the grouping of machines and personnel; the level of technology used in workflow design and the level of technology used in the information system. The specialization that has now become associated with production systems has been an ongoing area of interest since the beginning of the century and refers maily to a breakdown of the total work task into extensively subdivided tasks. One of the ways in which this drive to sustain productivity has been maintained is through the use of simulation as a decision making tool.

Simulation and simulation techniques have been used for more than 30 years in the UK, evidence (Hollocks, 1992; Robinson and Pidd, 1998; Hlupic, 2000; Murphy and Perera, 2002) gathered, suggestes that there is a relatively low level of usage withing the maufacturing community. Even after a large survey was conducted by Hollocks (1992) almost 15 years ago, found that the trend has not changing significantly. Previous research carried out in the field of simulation by (Tjahjono and Baines, 2004) in the East England region showed that of all the manufacturers surveyed only around 20% of them had applied simulation techniques as a decision making tool. A further 40% of manufacturers within that region were not aware of the capabilities of simulation tools or even how to apply them to the decision making process. These findings led them to identify three major barriers that caused this low uptake of simulation as a decision making tool them being;

- Compared to the ordinary desktop applications that are currently in use, simulation tools are far more difficult to understand and as a result they require specific skills in order to operate them.

- Simulation tools in the context of a small or medium sized manufacturing environment in most instances are too powerful for the problems being addressed and as a result they can become expensive to acquire.

- The process of building, verifying and validating simulation models can be very time consuming and resource intensive.

Through the adoption of simulation techniques as both strategic and operational decision making tools it is hoped that manufacturers will be able to make effective decisions, thus enabling them to increase competitiveness and ensure a prolonged future for UK manufacturing. The ability to make effective decisions is, in fact, one of the crucial factors to increase competitiveness and ensure the future of UK manufacturing (DTI, 2004). The work carried out in this thesis details the evolutionary approach to simulation model building through the uses of cladistics and template based model libraries. More information regarding the outline of the thesis shall be presented in section 1.6 of this report.

1.1 Background

In today's marketplace we see that although the manufacturer of products are many and varied, most manufactures regardless of their product, tend to share a common set of problems. These problems usually take the following forms, some of them being: optimising plant capacity, establishing the minimum inventory levels needed the minimisation or elimination of production bottlenecks, co-ordinating logistics within the supply chain environment and to a great extent the scheduling of day to day work orders through the manufacturing environment. The drive towards a more globally competitive and dynamic market has increased the pressure on manufacturers for increased demands of goods and services, some with a wider product variety, faster delivery times, improved quality and reduced cost. These factors in turn contribute to an ever increasing demand for more innovative manufacturing systems which are capable of matching this pattern of ever increasing demand. However the design of an effective and innovative manufacturing system is a difficult task, as most manufacturers usually have no means of obtaining early indicators of production costs and or reliable process times. Also collection, storage and reuse of best practice manufacturing processes are never easy.

The level of financial investment required to fund any manufacturing process, whether it is the design of a new or the redesign or an existing system can be huge financial gamble and the consequences of a poor system design can be catastrophic to the business as a whole. The tools, techniques and technologies, therefore, need to be methodically chosen and skilfully applied to address these problems. One of the most powerful tools that industrialist have at their disposal when it comes to the design or redesign of manufacturing systems is that of Discrete Event Simulation or simulation as it is more widely known. Discrete event simulation involves modelling a system as it changes through time and is of particular use when it comes to the analysis of part queuing or part holding systems. These systems are a common occurrence within the manufacturing environment and can take the form of buffer stock, warehouse parts and work in progress. Commercial simulation tools usually feature computer-based graphical animations which mimic the behaviour of the manufacturing system being modelled.

A major advantage to the use of discrete event simulation lies with its ability to model random events and to predict to a very high extent, the effects of the complex interactions between these events. System manipulation can be carried out using software models to generate answers to what-if?, scenarios which may occur within the production system. The results obtained are achieved by varying the inputs to the model and then comparing the outcomes. Driven by the need for and the demand to quickly introduce new products into the marketplace, combined with having to tailor to specific customer requirements, companies are now moving away from the traditional approach of mass production and towards one of mass customisation. With this in mind we see that the application of simulation enables manufacturers to carry out “what-if” scenarios that are useful to gain a deeper understanding of how a new or alternative manufacturing system will perform before any investments or modifications are made.

1.2 Problem Statement

The challenge faced by this research is how to improve the ability of UK-based manufacturing industry to make a more effective decision during manufacturing systems design/redesign through adoption of simulation techniques as both strategic and operational decision making tools. The aim of this research is to develop a classification scheme based on cladistics and evolutionary analysis and to use this classification in the development of a template based modelling library. The focus of this research will be on existing manufacturing systems, layout configurations and template model generation.

1.3 Introduction to the Research

As a result of this increase in rate of global productivity and demand, production systems are being designed and redesigned at an increased rate and they are becoming more innovative as they progress with time. To describe any given manufacturing system there needs to be an outline of both the organisational and the technological variables which determine their level of functionality. Most initiatives which are used to improve processes within a manufacturing environment tend to manual in their implementation, expensive to implement and time consuming to change. This can be mostly attributed to the complex nature of process design and redesign. Within the manufacturing community there is a need for the development of a fast, easy to use and reliable solution to the problem of simulation modelling. The research detailed in this thesis looks at using cladistics and template based modelling to aid in the rapid design of simulation models and the development of a modelling tool (RapidSim) for use within the manufacturing environment.

1.4 Research Deliverables

There are three principal deliverables that will be disseminated and exploited through a number of routes.

1) The first deliverable is the knowledge of layout model patterns that exist within the manufacturing systems identified. Information on the various layout types which are used in industry to date is compiled and classified by using cladistics and evolutionary analysis so as to develop a classification system. Developing this classification system enables a novel and innovative way of rapid model conceptualisation and assembly which will be a valuable contribution to the simulation community.

2) The second deliverable is the development of a template based modelling library which has been developed in conjunction with the derived cladistical classification. The template based library will facilitate the quick and easy assembly of simulation model components making it easier for the end user to develop and build a simulation model. The template based library will also facilitate the concept of model use and reuse thereby allowing different models to be built from the same key components.

3) Finally the third deliverable is a prototype of the rapid model generator. The RapidSim interface will be designed with the intention of guiding the user through a quick and smooth model building process by making the simulation modelling process faster and easier to use. The interface will be designed using Microsoft excel and will be programmed using Microsoft visual basic. The design of the interface is aimed at giving end user’s an easy approach to the selection and modelling of layout types which in turn will help reduce the time it takes to build a simulation model.

1.5 Proposed Conceptual solution

The difficulty in providing the most appropriate simulation template in order to speed up the construction of manufacturing models is largely due to the fact that manufacturing systems, and more importantly, the problems and hence the associated types of decision making, are not well categorised or classified. Previous work carried out in generic template generation for simulation models has been solely based upon the systems physical layouts (e.g. assembly facilities, cellular layout) but not necessarily based upon the problems that a simulation study will address. For example, a typical problem in manufacturing to be solved using simulation is to identify the bottleneck, which usually leads to the identification of the appropriate buffer locations (and sizes) to overcome this bottleneck. Optimising buffer sizes and locations would also address the problems in minimisation of work-in-progress (WIP). From this example, it is apparent that the goal of a simulation model may evolve from tackling one problem to another. For this reason, a new method of developing simulation model templates is required, allowing simulation models to be generated based upon similarity of problems being addressed and hence the similarity of the decision to be made. Therefore, two models with completely different layouts may share the same model template because they also share similar problems. One of the possible ways to facilitate this is by applying a classification method. It is proposed that cladistics be used for this research in order to develop the classification method.

A classification "arranges materials in a way that tells us something about them: a mere list has no such character" (Ghiselin 1997, p. 301) and a good classification provides "a system which has high predictive value and will allow maximum information retrieval" (Mayr 1969). Cladistics is a purist approach to the phylogenetic principle and the evolutionary classifications developed tend to be a combination of the phenetic and phylogenetic principles. The end product of any cladistical analysis is the generation of a system cladogram. Cladograms can be described as tree like diagrams which display the relationship patterns which has been established amongst entities or clades as a result of their shared or derived characteristics. The limbs or branches of the tree diagram are used to represent the taxa while the tips of the branches are used to represent the species.

Cladistics was chosen for this research primarily because the cladistical approach to formulating a classification system entails a study of the evolutionary relationships which occur amongst entities with particular reference to the groups common ancestry. Any classification which is derived from an evolutionary relationship is deemed as being beneficial to the system as the classification will be both unique and unambiguous. The use of cladistics satisfies both of these criteria as the entities making up the classification tend to resemble each other in regards to both defining and non defining characters. Cladistics is also viewed as being objective as it represents the unambiguous and natural property of the entity and as such different individuals, working independently of each other should be able to agree on a classification. The strength of the cladistical approach lies in its representation of the classification as the cladogram helps in illustrating the analysed data and results thereby making all decisions transparent.

McCarthy, Ridgway and Fieller, through an EPSRC project (grant number GR/K97974/01), studied and compared a number of methods drawn from the science of diversity, systematic and biological taxonomy, and formulated the guidelines and principles for manufacturing systems classification. Cladistics was used to "analyse the diversity of the automotive assembly industry and to identify their characters which will not only enable grouping, but also will help them clearly identify the characteristics which are appropriate for their business needs" (McCarthy et al., 1997). Cladistics has also been applied in other areas, for example electronics manufacture (Fernandez & McCarthy, 2002) and hand tool manufacture (Leseure, 2000). In the context of organisational change, cladistics has been applied in benchmarking (Fernandez et al., 2001), measuring agility (Tsinopoulos and McCarthy, 2000) and change management (Rakotobe-Joel et al., 2002).

The novelty of the proposed research will test the boundaries of current and releated research in the field of rapid simulation model generation and template based modelling. It is envisaged that the work proposed in this research will aid in substantially advancing the knowledge from previous carried out work by:

- Using cladistics and evolutionary analysis as the basis for a classification of manufacturing systems layout types.
- Investigation into a new and novel approach to the rapid generation of simulation model templates based on the manufacturing layouts identified.

- Changing the approach to simulation model development from one of 'model building' towards one of 'model assembling'. The development of a ready to use component library which facilitates the easy retrieval of model elements as well as the automatic generation of the completed model will be used to speed up the model building process.

1.6 Outline of the Thesis

The outline of the thesis shown in figure 1 below is as follows;

Chapter 1

Chapter 1 gives an introduction to the research which has been carried out in this thesis. The work detailed in this covers the background to the research, the problem statement and a brief introduction to the research is also given. The research deliverables are also highlighted along with the proposed conceptual solution to the problem

Chapter 2

Chapter 2 provides a review of the literature surrounding the subject of rapid simulation building, template modelling, cladistics, evolutionary analysis and includes such themes as:

- The research aims and objectives as well as the questions which are used to guide the research
- The search strategy used to obtain the relevant information
- The results and analysis of the data search
- The key findings obtained
- The research gaps

Chapter 3

Chapter 3 covers the research methodology which has been used to carry out the research process. It looks at the different types of research methodologies which can be used when doing research and highlights the methodology chosen for this research. It also identifies the research problem area as well as the way in which the research has been focused in order to meet its objectives. One of the most important aspects of this chapter is that it details the necessary work which needs to be carried out via the research work packages

Chapter 4

The focus on this chapter is in establishing the model pattern of manufacturing systems and the different manufacturing types identified from the literature review are discussed. This chapter also details work done in the field of simulation model development with regard to the need for simulation and the use of conceptual modelling. The classification of manufacturing system types is also presented in this chapter.

Chapter 5

In this chapter the use of cladistics to develop a template based model library is discussed. The chapter starts off by presenting some general information on cladistics as well as information on how cladistics has been used within the manufacturing industry. A detailed description of the cladogram building process as well as the cladogram generation process has been developed and discussed. Analysis of the developed cladogram is also presented in this section of the thesis.

Chapter 6

The work presented in chapter 6 covers the development of the rapid model generator prototype (RapidSim). The information presented in this section covers the areas of simulation module creation and use in industry, generic simulation module creation and module creation using cladistics. Attention is also focused on the creation of a model based template and the development of a template based model and model library. Information on the RapidSim interface is also presented in this section of the thesis.

Chapter 7

In this chapter the validation methodology used to validate the research carried out is examined. Information regarding the overall validation process is discussed and the experimental case studies used in testing the interface is presented. The experimental results from the case studies are detailed along with a discussion of the results obtained and an overall discussion of the validation process.

Chapter 8

This chapter outlines the additional enhancements which could be made to the field of simulation and modelling to improve its performance. A discussion of the findings and the conclusions of the thesis are also provided in this chapter.

The full outline of the thesis can be seen in figure 1.

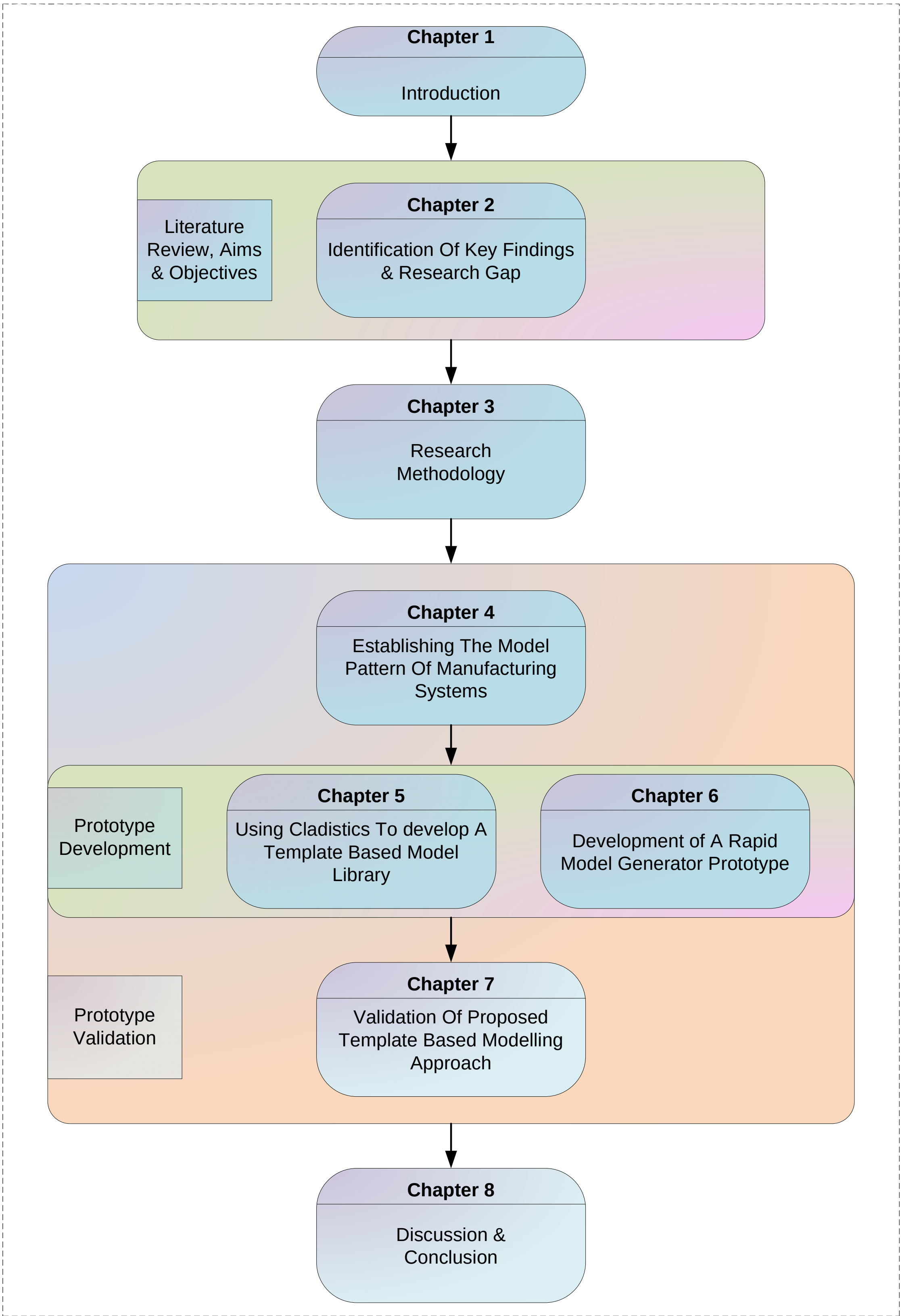


Figure 1: Outline of the thesis

1.7 Summary

The work detailed in this chapter outlines the main research themes of the thesis. A brief background into the need for simulation within the manufacturing industry has also been explored. A summary of the chapters that make up the thesis has also been provided. The work presented here has also discussed the following;

- The research problem statement
- The research deliverables
- The proposed conceptual solution

The main focus of this research is to develop a template based modelling library which is based upon the use of cladistics and evolutionary analysis. The focus of this research will be on the different types of manufacturing layouts that exist, their elemental composition and how this can be used in developing a rapid model generator for simulation modelling. Chapter 2 details the literature review which has been undertaken in the completion of this thesis.

Chapter 2

Literature Review

2 LITERATURE REVIEW

2.1 Introduction

A number of areas have been investigated during the course of this research in order to develop the modular approach to rapid simulation model building. Research has also been made into the fields of simulation and modelling as well as in the fields of cladistics and manufacturing systems layout types. Similar work has been conducted into the existing process of modular template based libraries and the simulation problems they aim to solve. The review carried out in this chapter is a summary of the investigations in the field of rapid simulation model building. A subsequent review of literature on manufacturing systems layout types and cladistics can be found in chapter 4 and 5 respectively.

2.2 Research Aims, Objectives and Questions to Guide Research

The overall aim overall aim of this research deals with investigating a new method of rapid simulation model development, using template based modelling patterns which are based upon cladistics and evolutionary analysis. The main objectives that need to be fulfilled in order to achieve these aims are as follows;

- To collect information on the different manufacturing systems which exist in order to promote some understanding of the diversity and types of manufacturing systems?

- To apply cladistics and evolutionary analysis to classify theses manufacturing systems based on their physical layouts and characteristics.

- The use of this classification system as the basis of the model library.

- The development of a rapid model generator using a discrete – event simulator, whereby these components are retrieved from the model library.

- To evaluate the feasibility and usability of the method and prototype within the manufacturing industry.

In determining the extent of this research the primary focus has been on articles that are central and relevant to the themes of simulation and modelling; template based modelling; template based modelling library creation; manufacturing layouts types and the use of cladistics. The manufacturing system characteristics needed for generating the cladogram could be obtained either through a collection of the literature written on the subject matter or through a quantitative survey. Using a quantitative survey which comprised of a questionnaire followed by structured interviews of simulation experts was considerd as the primary data collection tool at the start of the project. However this method was dropped as the the primary data collection tool in favour of a detailed literature review as an analysis of the literature that is sufficiently accurate and representative of the data would be better suited for this study as opposed to the use of survey. The use of a survey posed some potential problems in respect to the collection, accuracy and analysis of the data and as a result was dropped as a data collection tool. Also, the examples of manufacturing types and layout configurations collected from the literature review were considered as being more relvant as information on these systems had been accepted and published by persons relevant to the field of manufacturing systems.

Papers which highlighted the areas of interest mentioned above were all considered as being relevant to the data collection process. One such example of a publication which falls within the scope of this review is; Williams & Chompuming (2002) where the authors discuss a robotic workcell with specific reference to I-beam welding. To aid in the data collection process a series of questions were posed with the intention of ensuring a thorough and comprehensive analysis of publications relevant to these fields of study. It should be understood that these questions may not necessarily lead directly to any research findings. The questions are as follows:

- What is meant by the term “layout” and what are the common types of layouts used?
- What makes one layout different from the other?
- What reasons exist for the low uptake of simulation in industry?

- What is cladistics and how has it been used in the manufacturing sector?
- Has cladistics been used for simulation in non-manufacturing fields?
- What is the modular and template based approach to simulation modelling?
- How are components used and reused in the simulation model building process?
- What problems associated with the use of modules for model building?

These questions highlight the fact that this study has focused exclusively on the literature currently associated with manufacturing systems layouts, cladistics and template based simulation modelling. Publications which fell outside of these guidelines were deemed as inappropriate and uninformative and therefore not included in the review. The research presented in this thesis deals with the identification, interpretation and classification of the different types of manufacturing layouts which are used throughout the manufacturing sector by applying cladistics as the classification tool. It also focuses on how this cladistical classification can be transformed into a template based modelling library which can be used to rapidly design and re-design simulation models.

It is hoped that this study will promote greater understanding of the diversity and types of manufacturing systems which exist by identifying and explaining the various layouts types used in these systems and how through the use of cladistics, these systems can be classified based on their similarity of physical characteristics. It is also envisaged that the research presented here will help promote further development in the field of template based simulation modelling.

2.3 Scope of the Literature Review

The research undertaken in this thesis aims at bringing about an answer to the low uptake of simulation and modelling within the manufacturing sector. A review of literature pertinent to this field of research has been carried out in order to gain a better understanding of how researchers have dealt with this problem in the past. The review exercise is the key to gaining a clearer picture of the conceptual solution needed and it also identifies the gaps in the knowledge when dealing with template based modelling libraries, rapid simulation modelling and model generation. A review of the literature pertinent to the field of simulation model building was carried out in order to identify the various ways in which the speed of the model building process could be enhanced. The bulk of the review was made up of information gathered from journal papers and conference proceeding with specific reference to simulation model building and module libraries.

Articles describing the application and use of component based simulation modelling gathered from the Winter Simulation Conference proceeding (1998 – 2010) were considered as being relevant as they highlighted the usage and also the problems of component reuse. The theme set for this research can be illustrated by the work carried out by Son et al, (2000) writing in the proceedings of the Winter Simulation Conference. The authors studied “the proposed development of neutral libraries of simulation components so that the availability of such libraries would simplify the generation of simulation models, enable component-based modelling, and provide internet-based simulation services” (Son et al, 2000).

Model building is one of the key steps in any simulation study that requires simulation modellers to fully understand the problems, envisage and construct the model elements and identify the relationships that logically link those elements together (Guru & Savory, 2004). Robinson & Bhatia (1995) described that "model building (and testing) can take up almost 40% of the total simulation study time to ensure that the simulation model is *credible"* (Law & McComas, 2001), i.e. if the model is acceptable by the simulation users. Furthermore, Willemain (1995) argued that almost 60% of the model building time was spent solely on understanding and developing the structure of the model. As with previous studies (Hollocks, 2001; McNally and Heavey, 2004), in the case where simulation is widely adopted in industry, Tjahjono and Baines (2004) reported that there has been an increasing trend towards the use of simulation by people who are not necessarily experts in simulation, such as manufacturing engineers, production planners, etc. For that reason, approaches have been taken to make simulation tools easier to use, which in turn will speed up model building. This includes the creation of a secondary user interface for data input/output (McKenna and Little, 2000; Ladbrook and Januszczak, 2001), rationalisation of data format (Robertson and Perera, 2002), the use of component modelling (Pidd et al, 1999) and model building using a predefined template (McLean and Leong, 2001).

A template, in the context of simulation and modelling, is referred to as a collection of user-defined, ready-to-use and re-usable building blocks that are created by programming their functionality, interface and performance indicators in an appropriate simulation environment. Thesen (1990) developed a template-based simulator to analyse a material handling system for inspection and repair workstations on a manufacturing shop floor. A generic model was used to describe parts and resources in independent templates that run on a simulation engine designed to incorporate random part routing with branching. Pater and Teunisse (1997) used model components in a library to model the new railway cargo line connecting Rotterdam harbour with the Ruhr, the industrial estate in Germany. The model is used to study whether the capacity of the railway meets the requirements.

Appleton et al. (2002) described a special purpose simulation template which is based on the tower crane operations. The approach has addressed problems with a large amount of work tasks for the tower crane resource, resulting in the increase in model complexity and traditional simulation techniques become unmanageable. Mukkamala et al. (2003) developed a "domain-specific template for the automated assembly of printed circuit boards", based upon the work of Farrington et al. (1996). Modelling efforts can be reduced to a great extent through the development of domain-specific modules or templates that encapsulate the domain-specific logic and hide many of the modelling details. Winnell and Ladbrook (2004) developed a component-based simulation extension to an existing simulation tool to enable modelling of car engine assembly lines.

Research carried out by the Integrated Manufacturing Technology Road mapping (IMTR) Project Team concluded that “Modelling and Simulation are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more than a fraction of the potential that M&S does for improving products, perfecting processes, reducing design-to manufacturing cycle time, and reducing product realisation costs" (McLean and Leong, 2001). From the conclusions of the IMTR project it has become evident that the use of simulation and modelling be made more users friendly and more accessible in order to enhance its application as a planning and decision making tool. The day to day decisions which are taken within companies often have to be taken in consideration of multiple independent factors and variables. This process is often very complicated and according to (McLean and Leong, 2001; Heilala et al., 2007), these decisions "are probably too many for the human mind to deal with at one time". The complex nature of simulating manufacturing systems combined with the timely and costly process of simulation model building means that more innovative and faster methods of constructing simulation models need to be developed.

As greater advancements have led to changes within the manufacturing sector this however has not led to an increase in the uptake of modelling and simulation with commercial based software. The process of building a simulation model from a commercial off the shelf software (COTSS) can be a very time consuming and requires a great deal of effort and expertise. The use of commercial based software packages can be used to build a simulation model from scratch through the use of graphical based interfaces thereby reducing the effort involved in the level of programming needed (Mueller et al., 2007). Mueller et al., (2007), goes on to state that there exists the "need for the efficient and effective method for simulation model development which will allow simulation users to accelerate the process of producing correct and credible simulation models". However Brown and Powers (2000), noted that creating a model from scratch can be an over whelming task.

The concept of modular simulation building has been around for some time and work carried out by Zeigler (1984) proposed "a methodology to formalise the modular and hierarchical construction of simulation models" shows that modular construction is an on-going theme. Pidd (2004), advocates that the modular approach to model building is beneficial as "a method of dealing with the increasing size and complexity of simulation models". Kilgore et al (1998) goes on to state that "modules when developed and standardised as simulation components, may reduce the intricacies of the modelling task". The literature review revealed that many of the solutions which have been adopted by researchers and industries, are "often customised to a very specific domain, for example tunnelling operations or railway lines, and were developed to fit within the framework or programming paradigm of a particular commercial simulation tool. The implication is that additional work is often required to customise the template, which often demands even more expertise in using a particular simulation tool. Second, the models generated using templates are generally limited to systems with regular patterns" (Tjahjono, 2007).

"The development of High Level Architecture (HLA) and the widespread use and accessibility of World Wide Web has furthered interest in the concept of model reuse" (Robinson et al,2004). The concept of model reuse is becoming more accepted within the simulation modelling community. The idea that modellers can reuse simulation models and components developed either by themselves or by others as a means of saving time, money and effort was found to possess certain merits with advances in technology leading to this idea becoming more viable than before. Model reuse is a systematic process which emphasises the maximum usage of existing models or modules so as to avoid model repetition, saving time and money in the process. The concept of model reuse has become favoured within the modelling community as a "more cost effective, faster development and easier maintenance of complex models" (Daum and Sargent, 1999). "The key to simulation model reuse is to enhance the reusability of model itself, which can be achieved by fostering reuse-oriented modelling idea and providing supporting techniques for reuse" (Lei et al., 2007).

Lei et al., (2007) goes on to state that "A unified simulation model representation is one of the key techniques to facilitate model reuse". Heilala et al., (2007) takes this argument even further by "suggesting that component based simulation is advantageous to the model building process as it reduces the time taken for model construction especially if pre-engineered components are at the modellers disposal". Expanding on this them Heilala et al., (2007) goes on to state that the model building process focuses on “configuring a layout, by selecting the right components to fulfil the process flow and setting the right parameters” “The development of neutral, vendor-independent data formats for storing simulation models could greatly improve the accessibility of simulation technology to industry by enabling the sharing and re-use of models” (McLean and Leong, 2001). Neutral simulation templates would aid in common model development as the constructed models would be available for use by a wide range of users including individual companies, consultants etc. In developing the idea of neutral based libraries McLean and Leong (2001) suggested that “Simulation study templates for addressing classes of simulation problems, building block modules of manufacturing system components to be used in the templates and libraries of simulation reference data sets should be developed”.

Using a neutral template based modelling library facilitates the “reuse of simulation models from different simulators in different simulation scenarios with room for distributed simulations between different enterprises without the necessity for these enterprises to use the same simulator” (Mertins et al., 2000). The template based library containing the completed modules can be stored in a relational database which is built upon the principles of Ontology. Benjamin et al., (2006) describes the concept of ontology "as a useful tool in the simulation modelling and analysis lifecycle especially in the problem analysis and conceptual model design phase". He discusses the advantages and challenges in the use of ontology in simulation modelling. "Ontology development focuses on extracting the essential nature of the concepts in any domain and representing this knowledge in a structured manner” (Benjamin et al., 2006).

2.4 Search Strategy

In order to collect the relevant data on the different manufacturing layouts which exist, the author had to carry out a review of the literature relevant to this particular field. In order to make this process as efficient as possible a search strategy was formulated to aid in the data gathering process. The search strategy was based on identification of the relevant data sources and keywords and focused its attention on gathering information from a wide classification of databases, conference proceedings, books, library catalogues and articles from online journals. Some of the databases searched included SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry, Aerospace and High Technology Database (CSA) and ScienceDirect via SCIRUS (Elsevier). The parameters of the search strategy were further narrowed by defining the timeline for publications which would be considered. The search focused on the more recent publications and as such only papers written and published between 1997 and 2011 were considered for the review. As greater innovations are being made in the field of manufacturing, limiting the search to a specific time frame was done in order to keep the search focused on the most recent publications and innovations in the field of template based modelling. However any landmark publications that were deemed as being relevant to the review before that time period were also considered.

These databases provided access to numerous publications such as the Proceedings of the Institution of Mechanical Engineers, European Journal of Operational Research, Journal of Computers & Industrial Engineering, Journal of Robotics and Computer-Integrated Manufacturing, Journal of Simulation Modelling Practice and Theory, International Journal of Operations & Production Management, the International Journal of Advanced Manufacturing Technology and the Journal of simulation. Conference papers from the winter simulation conferences were also included in the search. The search strategy used a wide range of keywords such as simulation and layouts, and various keyword combinations such as "Machine and Plant Layout", "Type of Machines and Manufacturing Problems", "Simulation and Manufacturing Classification", “simulation”, “module”, “neutral libraries” “rapid model generation” but to name a few. Wildcard searches were left out from our search strategy as they increased rather than decreased the bandwidth of our search, fetching up to 10,000 hits per search string in some instances.

The theme of the research was best illustrated through the papers written by Brown and Powers (2000) titled “Simulation in a box” and by Guru and Savory (2004) publication titled "A template-based conceptual modelling infrastructure for simulation of physical security systems". The information presented in these papers led to the discovery of more publications in this area of research. Upon collection of information the list of hits for our search had to be firstly reviewed then edited so as to omit any duplicate records which may have appeared. The articles were then checked to ascertain their relevance to the review. Also an internet based search was carried out using a similar process to complete the information collecting exercise**.** Tables 1, 2 and 3 shows the search words used in the database search, some of the conference papers collected as well as some of the journal papers reviewed at this stage of the research.

Table 1: The Search Words Used and The Results Obtained.

Key Search Words	Databases Searched	Total Hits
"Machine" and "Plant Layout"	SCOPUS, ABI/Inform Trade & Industry (ProQuest)	985
“Changing Products” and “Manufacturing Systems”	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	127
"Problems" and "Machine Objectives"	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	183
"Specific machines" and "Objectives"	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	129
"Types of Machines" and "Manufacturing Problems"	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	94
"Simulation" and "Manufacturing Classification"	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	49
	Aerospace and High Technology Database (CSA)	
	Science Direct via SCIRUS (Elsevier)	
"Simulation Templates" and "Manufacturing Layouts"	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	148
“Discrete event simulation” and “Templates”	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	112
“Discrete event simulation” and “Rapid model generation”	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	121
	Aerospace and High Technology Database (CSA)	
“Discrete event simulation” and “Model reuse”	SCOPUS (Elsevier), Science Citation Index (ISI), ABI/Inform (ProQuest), ABI/Inform Trade & Industry	76

Table 2: Examples of Conference Articles Collected

Author	Title	Source
Claudio et al (2007)	A Hybrid inventory control system approach applied to the food industry	Proceedings of the 2007 Winter Simulation Conference
McLean and Long (2001)	The expanding role of simulation in future manufacturing	Proceedings of the 2001 Winter Simulation Conference
Chong et al (2006)	A bee colony optimization algorithm to job shop scheduling	Proceedings of the 2006 Winter Simulation Conference
Brown and Powers (2000)	Simulation in a box (A generic reusable maintenance model)	Proceedings of the 2000 Winter Simulation Conference
Craig W. Alexander (2006)	Discrete event simulation for batch processing	Proceedings of the 2006 Winter Simulation Conference
Guru and Savory (2004)	A template based conceptual modelling infrastructure for simulation of physical security systems	Proceedings of the 2004 Winter Simulation Conference
Esra E, Alesia & Li Lin (2005)	For effective facilities planning : Layout optimization then simulation, or vice Versa	Proceedings of the 2005 Winter Simulation Conference
Curcio et al (2007)	Manufacturing process management using a flexible modelling and simulation approach	Proceedings of the 2007 Winter Simulation Conference
Mertins et al, (2000)	Neutral template libraries for efficient distributed simulation within a manufacturing system engineering platform	Proceedings of the 2000 Winter Simulation Conference
Mackulak et al, (1998)	Effective simulation model reuse. A case study for AMHS modelling	Proceedings of the 1998 Winter Simulation Conference

Table 3: Examples of Journal Articles Collected

Author	Title	Source
Boysen, et al (2007)	A classification of assembly line balancing problems	European Journal of Operational Research
Schaller (2007)	Designing and redesigning cellular manufacturing systems to handle demand changes	Journal of Computer and Industrial Engineering
Castillo, et al (1997)	The development of a cellular manufacturing system for automotive parts	Journal of Computer and Industrial Engineering
Potts & Whitehead (2001)	Workload balancing and loop layout in the design of flexible manufacturing system	European Journal of Operational Research
Quadt & Kuhn (2007)	A Taxonomy of flexible flow line scheduling procedures	European Journal of Operational Research
Abdi & Labib (2004)	Grouping and selecting products: the design key of reconfigurable Manufacturing Systems (RMSs)	International Journal of Production Research
Askin; et al (1997)	A methodology for designing flexible cellular manufacturing systems	Journal of IIE Transactions
Blazewicz; et al	Vehicle scheduling in two cycle flexible manufacturing systems	Journal of Mathematical and Computer Modelling
Sodhi and Sarker (2003)	Configuring flexible flowlines	International Journal of Production Research
Hoda & Maraghy	Flexible and reconfigurable manufacturing systems paradigms	International Journal of Flexible Manufacturing Systems
Zolfaghari & Lopez Roa (2006)	Cellular manufacturing verses a hybrid system: a comparative study	Journal of Manufacturing Technology and Management

2.5 Results and Analysis

The information represented in table 2 and 3 shows a sample of the papers collected over the given time period. The information compiled in the tables was structured so as to identify the author, the year published and the environment in which the layout was used. The author identified a total of 250 publications; each detailing a particular manufacturing layout represented either pictorially or descriptively.

The information collected was also clasified based on the percentages of papers collected in relevance to the year they were published. The highest number of papers collected came from 2008 yielding18%, whilst the second highest number came from the year 2000 yielding 12%. Years 2005 – 2007 yielded 10% each as did 1998. These years accounted for 70% of the papers reviewd with the remaining 30% coming from the remaining 12 year period. The highest number of papers was collected in 2008; the number being 45 followed by 30 papers for 2000 and 25 papers each for 2005 - 2007 and 1998. This accounted for 55% of the papers collected with the remaining 45% made up from the remaining 10 years.

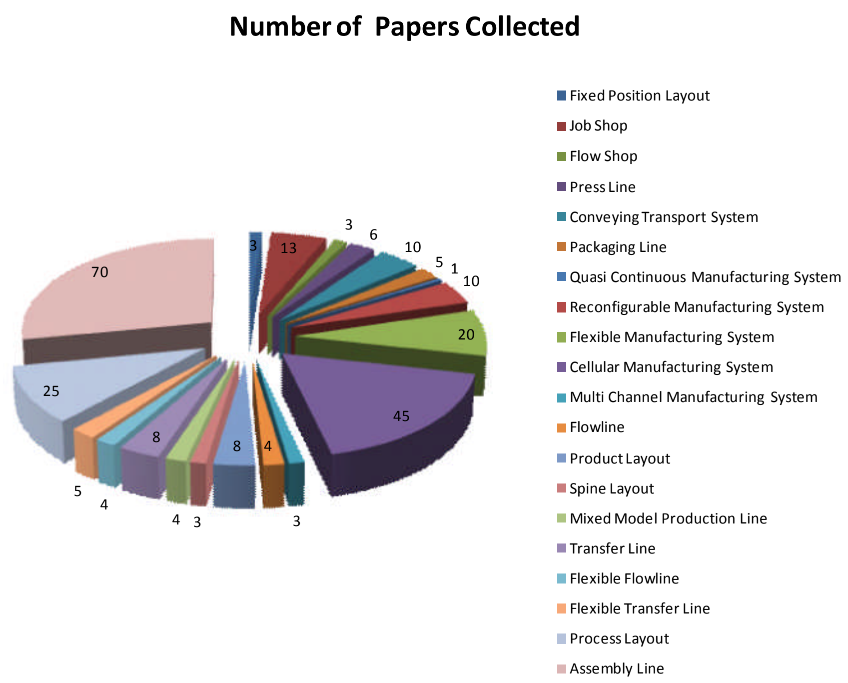


Figure 2: The Number of Papers collected

Figure 2 shows the various types of layouts which have been identified via the data collection process and the number of papers which have been collected on those layouts. The highest yield of papers came from the analysis of assembly line systems, followed by information collected on cellular manufacturin and process layouts. These 3 areas accounted for the highest number of the papers collected as information on these layouts was readily available. On the other end of the scale some layouts for e.g. quasi continuous manufacturing systems only accounted for 1 of the findings as information on this system was realtively unavailble.

Figure 3 shows that the highest percentage of papers (34%) was established from information collected on assembly lines. This was followed by information reviewed on cellular manufacting and process layouts, yielding 22% and 11% respectively, with 8% of the total data collected coming from information on flexible manufacturing systems. These four areas accounted for 75% of the total papers collected. The outstanding 25% of papers came from information gathered on the remaining 16 layout types.

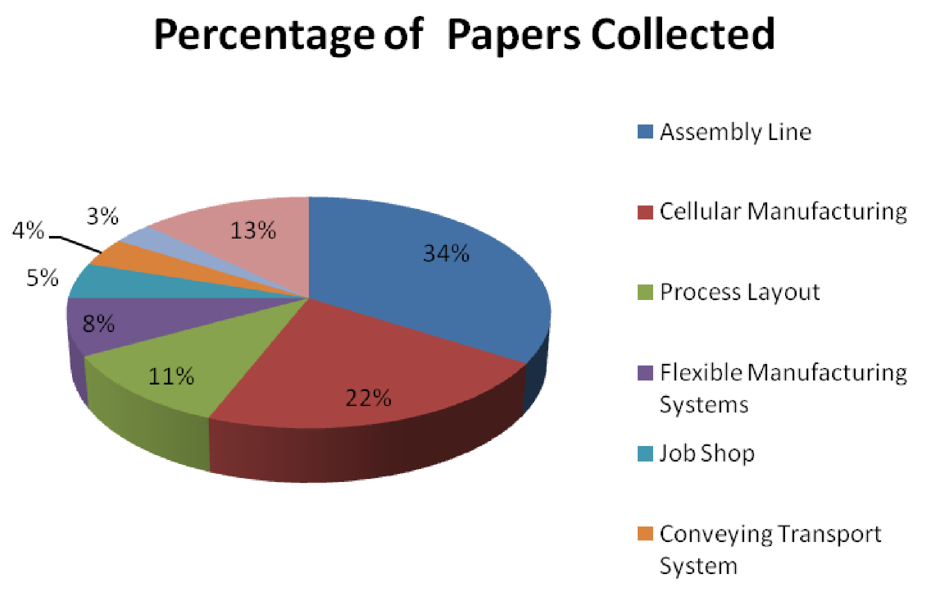


Figure 3: The Percentage of Papers Collected

2.6 Key Findings

The papers collected were summarised and the findings grouped together in response to the initial search questions posed. This process enabled the researcher to gain a deeper understanding of the concepts as defined in the articles, and at the same time brought out a number of key and emerging issues. These findings and issues are listed below;

Finding 1: The use of computer driven simulation and modelling has become an essential tool in maintaining productivity within the manufacturing sector as companies are driven to change in order to match the fluctuating patterns of consumer demand. The use of simulation tools that are easy to use, fast as well as being cost efficient are needed by manufacturers. It should also be noted that although simulation tools are essential they are also not well used within the manufacturing environment.

Finding 2*:* The following factors have, been identified through the course of this research, as contributing to the low uptake of simulation modelling. (More information regarding these findings can be found in *section 6.3* of this thesis)

- The cost of using a simulation based software package is not cheap and it is one of the factors which needs to be considered when undertaking any simulation based project. The cost of obtaining the relevant software licence is a major barrier to the increased uptake of simulation and modelling amongst users.

- The development of any simulation model, especially one which is built from scratch can be a very time consuming and labour intensive exercise.

- Most of the simulation models which are developed today rely on a significant amount of data in order to construct the model. In some instances this data may not be readily available to the modeller or modelling team.

- Another factor which needs to be taken into consideration in any simulation modelling exercise is the human factor. Developing and analysing computer based simulation models require specific skill sets in both the conceptual and computer based modelling environment.

Finding 3: In the context of this research, neutral based templates are templates based on manufacturing systems layout types which can be used and re-used in any given manufacturing system. The process of rapid simulation model generation can be made simpler by developing the concepts of neutral based templates, template based libraries, component modularisation and through the development of reusable generic module and model coding.

Finding 4: The introduction of reusable components within a simulation model can lead to the model generation process becoming more complicated. (More information regarding these findings can be found in *section 6.4* of this thesis)

Finding 5: The development of a neutral based template modelling library which houses the required simulation based templates and components is proposed as a means of dealing with the factors which inhibit the low uptake of simulation and modelling within the manufacturing sector. (More information regarding these findings can be found in *section 6.5* of this thesis)

Analysis of the articles collected from the literature review process has led to the identification of the following issues which needs to be addressed;

Issue 1: There are only a small number of industries which utilize simulation modules and simulation modelling as an aid in their day to day operations and decision making processes.

Issue 2: The modules which have been developed thus far all tend to be developed for a specific industry or system and as such they cannot be reused outside of these specified systems or parameters.

Issue 3: Developing and analysing computer based simulation models require specific skill sets.

Issue 4: Created modules are rarely reused. The developed modules as well as their templates must be easily accessible and their retrieval made easier so as to speed up the model building process.

2.7 Research Gaps

Despite the significant amount of work that has promoted the use of templates in simulation model building, the generality and the robustness of the application of such a method remains the gap that requires further investigation and validation, particularly within various manufacturing sectors. A thorough review of literature has consequently revealed the reasons for this gap.

1) Firstly, the solutions described are usually customized to meet the requirement of a specific industry for e.g. tunnelling operations or railway lines, and the framework for the templates are developed to fit within the operating parameters of a particular simulation engine. This often leads to the developer having to carry out additional work in order to customise the template which in turn requires greater levels of expertise in using that particular simulation tool.

2) Secondly, the generated models which have been created via the simulation templates are limited to systems that have regular or repetitive patterns, for example, machining lines in a car engine factory. The machining lines typically consist of a set of machines, followed by conveyors and buffers. A conveyor carries parts to be machined and a buffer stores the machined parts as work in progress (WIP). The 'conveyor-machine-buffer' configuration is in fact a building block that, because of its regular pattern, can be duplicated and linked together to construct a complete machining line.

3) Thirdly, manufacturing systems evolve over time. For example, Ford was once known as a craft manufacturer which then evolved further into a mass manufacturer and then into a lean manufacturer due to market competition. This means the problems being addressed by using simulation can also evolve depending on the systems being modelled. Although templates can be developed based on the similarity of the system's layout, the problems being addressed by manufacturers and the type of decision making can be completely different.

2.8 Summary

The literature review has examined the following areas concerned with this research;

- Simulation and modelling
- Modular approach to model construction
- Model libraries
- Template based model development
- Identification of research findings
- Identification of research gap

The findings of the literature review have helped to shape the focus of this research. Chapter 3 details the research methodology undertaken for this research.

Chapter 3

Research Methodology

3 RESEARCH METHODOLOGY

3.1 Introduction

The work presented in this chapter details the various research methodologies which are being used in the world of research. Methodologies such as ethnographic research, action research, case studies, experimental studies as well as the use of surveys will be discussed as this chapter progresses. This chapter will also look at the problem area which this research has been based upon and it will look at how the research has been focused in order to solve the problems mentioned.

This chapter details the research strategy which has been adopted for this research. The research carried out is a deductive one that employs the tools of experimental setup and retrospective studies to gather empirical evidence. This chapter also outlines the scope of the research as well as the methodology and the work package guidelines which will be followed in the development of this research.

3.2 The Research Methodology

Undertaking any research process or study in order to gain answers to specific question implies that

- The study is being carried out within a set of approaches or philosophies which have been adopted in order to guide the research.

- The research process employs the use of specific methods, procedures and techniques which have been verified for both their validity and reliability

- That the research process has been designed in such a way, as to be unbiased and objective.

Philosophies: When referring to the philosophies which have been adopted to guide the research one is in fact referring to the measures be they quantitative, qualitative or academic as it relates to your chosen field of research.

Validity: Ensuring that the research process and the results obtained are useful means that the correct procedures need to be adopted in order to find solutions to the questions posed.

Reliability: This relates to the quality of the measurement procedure which is being used to provide a measure of repeatability and accuracy.

Unbiased and objective: Each stage of the research process must be carried out in an unbiased manner without the deliberate attempt to conceal or influence the outcomes.

The process of conducting research can be described as the systematic procedure of collecting, analyzing and interpreting data in order to provide answers to specific questions. For any process to qualify as research the process must contain certain underlying features which are vital to the research process and these as far as possible must be controlled, rigorous, systematic, valid and verifiable, empirical and critical.

***Controlled**:* Any number of unknown factors which can potentially affect the end result of any research process. By exploring to the concept of control the research process is designed in such a way as to minimize the effect which unknown factors may have on the potential outcomes of the research process.

***Rigorous**:* A high level of scrutiny should be adopted so as to make ceratin the research procedures used in order to provide answers to the questions posed, are relevant, appropriate and justified.

***Systematic**:* The process which has been used to undertake any investigation must follow a clear, logical and sequential approach to solving the stated problem, as some procedures are sequentially dependant on the process before or after them.

***Valid and verifiable**:* Whatever conclusions that are drawn from the findings obtained must be correct and must be verifiable by yourself and by your peers.

***Empirical**:* Any conclusions which are arrived at must be based solely on the evidence gathered from the collected data.

***Critical**:* It is necessary to scrutinise the procedures and methods which have been used to carry out the research. The chosen method of investigation should be fool proof and free from any drawbacks that could affect the research outcome. The processes and procedures adopted to carry out the research must be able to withstand critical scrutiny.

According to Gill & Johnson, (1991) research can either be termed as being inductive or deductive. Inductive research involves moving from specific observation to the construction and explanations of broader theories and generalizations. “Theory is the outcome of inductive research” Gill & Johnson, (1991). Gill & Johnson, (1991) also go on to state that “deductive research entails the development of a conceptual and theoretical structure prior to its testing through empirical observation”. Deductive research works in the opposite manner to inductive as there is a shift from the more generalized theories and explanations to the more specific. Inductive research can be seen as being a “bottom up” approach whilst deductive research can be seen as being a more top down approach. There are two main approaches to dealing with the empirical studies them being: qualitative and quantitative respectively.

Bell, writing in (1997) describes the quantitative approach as a process which is based on the collection of facts, and the relationships that develop between one fact and another. The facts stated are measured by the use scientific techniques with the outcome being a quantifiable and generalised conclusion. The qualitative approach entails the understanding of individual’s perception of the world. “Insight is sought rather than statistical analysis” (Bell, 1997). “The choice of research methodology adopted for the study is dependent upon their research topic and research hypotheses” (Fitzpatrick *et al.*, 1998). The most important aspect of the research process is finding a balance between the conclusions obtained from the study and the situation being studied. The various research methodologies that are available for use in the completion of a research study are ethnography, action research, case studies, experimental, and surveys. Each method shall be explained in the following sections;

3.2.1 Ethnographic Research

The ethnographic approach to research data collection deals with the hands on approach of observing the participants of the study in their natural environments and in some cases partial or complete integration into the society being studied. Another tool used in ethnographic research is the interview. Interviews can involve conversations on many varied levels ranging from conventional small talk to the lengthy interview process. The use of ethnography allows the researcher the opportunity and the experience of observing the participants of the study more closely and it helps foster a better understanding of why participants behave the way they do. One of the main drawbacks to this type of research is that it is representative i.e. the populous sampled may not be a true representation of the wider group being studied and as such it can lead to the formation of generalized theories. However Bell (1997), states that “results may be relatable, and that other researchers can recognise the problems being addressed and see ways of solving similar problems in their own groups” (Bell, 1997).

3.2.2 Action Research

Action research can be seen as an interactive and practical approach to problem solving with the main aim of this approach being the improvement of practice. Action research has been designed as an on the spot procedure which deals with problems as they arise in immediate situations. It is a step by step process which is constantly monitored over time and through a number of different mechanisms. This ensures "that the feedback collected can be converted into modifications, adjustments, directional changes, redefinition, as necessary, so as to bring about lasting benefit to the on-going process itself" (Bell, 1997). With the assistance of professional researchers, action research can be used not only in the academic field but also by organizations and institutions who wish to bring about changes or improvements in their operational strategies and practices and to increase their knowledge of the environment in which they operate. This form of research is a direct challenge to the traditional approached adopted by the social sciences as it adopts the concept of active moment-to-moment theorizing and data collection. Knowledge is always gained through action and for action. From this starting point, to question the validity of social knowledge is to question, not how to develop a reflective science about action, but how to develop genuinely well-informed actions.

3.2.3 Case Study

A case study is a research method which is most commonly used in the social sciences and it can be described as a puzzle which needs solving. Adopting a case study approach allows the researcher a chance to do an in depth study of one particular problem over a given time period and it focuses on an inquiry around an instance. The evidence for the case study is collected in a systematic manner and the study is methodically planned. Case studies are made up of three basic steps;

The research phase: Literature pertaining to the case study needs to be collected as it is important to understand the problems you are trying to solve. The data collected may present important articles about the case as well theories and ideas that may or may not work for the case site. As well as gathering information from the literature another tool of the research phase is the interview process. When conducting interviews it is vital the right people are interviewed in order to obtain the right information. Asking questions which can help understand opinions and facts can help develop the case study and make it more reflective of the problems being investigated.

The analysis phase: After all the information regarding the case study has been collected it is necessary to put all the information in one place. As not all the information collected would be used for the case, having the information in one place helps with the sorting process ensuring that only the vital and necessary information is used.

The case write up: Presenting the case to the participants in the study is the final step in the case study process. It is always a good idea to try and formulate the case problem in a few sentences. This helps participants quickly understand what the case is about and it aids in the successful completion of the case exercise.

The best advantage of using a case study as a research tool is that it lets the researcher focus their attention on a specific problem allowing them to identify the various interaction processes which are at work. Case studies can be used either before or after a survey in order to get additional information or to identify key issues respectively. However it should be noted that when a case study is carried out by a single researcher there exists the possibility that the facts may become distorted and the information may not be cross checked. Bell, (1997), sums up by stating that the "Relatability of a case study is more important than its generalizability.

3.2.4 Experimental Study

Experimental research can be seen as both a systematic and scientific approach to the research process where the researcher manipulates the variables of the study and also controls and measures the resultant changes that occur in the other variables. Experimental research is most likely to be used under the following conditions;

- When the causes precedes the effects
- When there is consistency in the relationship (when a cause leads to an effect)
- The magnitude of the correlation is vast.

The term experimental research carries with it a wide range of definitions but strictly speaking the term is used to refer to what is known as a true experiment. There are three types of experiments in the experimental research process, true experiments, quasi-experiments and retrospective experiments.

True experiments

In a true experiment the researcher manipulates just a single variable whilst controlling the rest. In this regard a true experiment is usually undertaken under laboratory conditions so that a great deal of control can be used. Within the experiment the researcher manipulates the independent variable through direct intervention. In true experiments it is important to know the variable(s) that are to be tested and measured. The experiment usually contains a control group and an experiment group, with the subjects assigned randomly between the various groups allowing the researcher to test only one effect at a time. The effect of the independent variable is measured in the experimental group and not in the control group. Any changes which occur between the two groups as a result of the independent variable are monitored and measured.

Quasi-experiments

This type of experiment can be deemed as being an observational study which occurs within a real life environment. In this type of study the subjects to be observed are grouped together based on characteristics which they all possess rather than being randomly assigned to a different group. As the research takes place within a real situation the researcher loses some of the characteristics of the true experiment as they are unable to allocate subjects to the experimental and control groups in a random or systematic way.

Retrospective studies

This can sometimes be referred to as a historic study as it looks backward in time. In this study groups which are similar in many ways but which may differ by certain characteristic are compared in order to achieve a desired outcome. The study focuses on the cause and effect relationships which occur amongst groups by observing their present state of existence and then working backwards in time. The independent variable is not controlled by the researcher, instead the groups are examined in retrospect for possible connections which they may have to the variable. “Retrospective studies provide less convincing evidence about causal relationship but it is a useful exploratory tool” Robson, (1995).

3.2.5 Surveys

Surveys are used to gather information in a systematic and reliable way from all or some members of the sample populous chosen whereby allowing for the data to be analysed, patterns extracted and comparisons made. One of the most important aspects of any survey is the choice of the sample population. Great care must be taken when choosing this group as it needs to be truly representative of the population being studied. The financial cost of conducting a large scale survey of any kind can be very high, and it can also be very time consuming to conduct. With this is mind it is of the upmost importance that the data analysis carried out is as extensive and as well prepared as possible. The depth of the analysis is dependent on the quality and quantity of data that is collected. Over the course of the last few decades the survey has become the chosen tool of many governments, organisation and individuals as a means of collection information on a chosen subject from a chosen demographic.. A valid survey will in reality measure what it sets out to measure, but it should be noted that this is hardly ever the case, as many fail to do so. Designing a reliable survey means that you will get reliable results from repeated samples over time and that the differences in the results obtained tend to stem from the individual rather than from inconsistencies in how the questions are asked or answered.

3.3 Problem Area

Simulation and simulation techniques have been used for more than 30 years in the UK, evidence (Hollocks, 1992; Robinson and Pidd, 1998; Hlupic, 2000; Murphy and Perera, 2002) gathered, suggestes that there is a low level of usage withing the maufacturing community. Even after a large survey was conducted by Hollocks (1992) almost 20 years ago, the level of usage has not changed significantly. A recent study conducted in the East of England by (Tjahjono and Baines, 2004) revealed that only around 20% of manufacturers surveyed have applied simulation techniques as the decision making tool. More than 40% of manufacturers in the region were not even aware of the capabilities of the simulation tools or how to apply them properly. The study identified the three major barriers that caused this low uptake:

1) Compared to ordinary desktop applications, simulation tools are much more difficult to use and thus require specific skills to operate them. In fact, different simulation tools have different modelling paradigms and therefore need to be applied accordingly.

2) In most instances the simulation tools being used are far too powerful and advanced for the problem being addressed and as such, they can become prohibitively expensive to acquire. In addition, simulation experts are sometimes unaffordable by many manufacturers.

3) The process of building, verifying and validating simulation models can be time consuming and resource intensive. Furthermore, experimentation and analysis of results are complicated due to statistical analyses involved.

The challenge this research attempts to address is, therefore, how to improve the ability of UK-based manufacturing industry to make a more effective decision during manufacturing systems design/redesign through adoption of simulation techniques as both strategic and operational decision making tools. This research will also try to address the issues of cost and time consumption by developing a tool which is low in cost, fast and easy to use. The ability to make effective decisions is, in fact, one of the crucial factors to increase competitiveness and ensure the future of UK manufacturing (DTI, 2004).

3.4 Research Focus Identification

The detailed research work packages along with the intensive literature review that has been carried out has allowed for this thesis to be narrowed down to the aforementioned aims and objectives. The use of cladistics as a form of evolutionary analysis has helped shape the research reported in this thesis. The development of the classification system coupled with the cladistical analysis undertaken has led to the development and refinement of a template based modelling library which has been used in the development of the rapid model generator.

3.5 Research Work Packages

The overall aim of this research is to investigate a new method of rapid simulation models development using template and model patterns based upon *cladistics* and evolutionary analysis. The new method is believed to have a significant impact in disrupting the barriers to the use of simulation and modelling techiques via a reduction in the overall model development time, leading to a positive impact upon the uptake of simulation and modelling techniques within the UK-based manufacturing industry.

To achieve the research aim, a three-year research programme is proposed. The programme will have the following objectives:

- Collate and compare numerous types of manufacturing systems both in theory and practice in order to understand the different types of manufacturing systems
- Apply cladistics and evolutionary analysis to classify the manufacturing systems based upon their physical characteristics and the associated problems being addressed using simulation
- Use the classification scheme as a basis of the model library
- Develop a prototype of a rapid model generator using a discrete-event simulator where the components are retrieved from the library
- Evaluate the feasibility and usability of the method and prototype within manufacturing industry

A combination of survey, interview, tool development and experimental verification is chosen as the research methodology. To ensure that the project is manageable, a number of Work Packages (WPs) will be delivered throughout the research project. The tasks on each Work Package against the associated objective to be achieved and the deliverables are illustrated in the research methodology diagram shown in figure 4;

3.5.1 WP 1: Form Theoretical Knowledge Base of Manufacturing Systems

At this stage of the research it is vital that a thorough understanding of the diversity and types of manufacturing system layouts that exist be established. The main aim is the collection of information on the different types of manufacturing system models, based on the nature of their manufacturing processes, their typical layouts, material flows, routing logic etc., and to categorize this information into a classification system. The way in which this information will be collected is through a review of previous research and literature from various sources, predominately from journals and conference proceedings in the area of simulation and modelling. At this stage of the research, the main deliverable is an initial compilation and classification of manufacturing systems layouts. The main objectives that need to be fulfilled in order to achieve these aims are as follows;

- To profile manufacturing systems that use simulation.
- To promote some understanding of the diversity and types of manufacturing systems.
- The collection and compilation of an initial classification of manufacturing systems models.
- The reclassification of these systems based on their similarity of physical layout.

The formulation of this classification system will be used a reference upon which the foundation of the next chapter will be based.

3.5.2 WP 2: Establish the Model Pattern of Manufacturing Systems

In this work package, the theoretical classification of manufacturing systems models produced in WP 1 will be refined. It is proposed that the refinement will be carried out by verifying the classification produced with the real manufacturing systems collected from two streams of study: *a) survey of manufacturing companies and b) best practice study in model development*. For easy accessibility, Small and Medium Enterprises (SMEs) within the manufacturing sector in the East of England region are chosen as primary targets of the survey, although SMEs in other regions may also be contacted for further validation. A database containing approximately 2000 SMEs has been constructed from previous work (Tjahjono and Baines, 2004) in collaboration with the East of England Manufacturing Advisory Service (MAS East). The survey will be first carried out through questionnaires and then followed up by in-depth interviews to the selected participants. The study of model development practice will be conducted through interviews of simulation consultants and simulation tool vendors, to better understand the typical characteristics, properties and attributes of manufacturing simulation models they have come across. The refined classification of manufacturing systems models will form a *model pattern* that in the future will also act as a model library.

3.5.3 WP 3: Apply Cladistics to Develop A Model Library

The human desire to classify objects and information transcends all boundaries and disciplines no matter if the subjects being studied are mechanical, biological or chemical elements. For the purpose of this research the focus would be on the classification of the various manufacturing system types which exist. A classification "arranges materials in a way that tells us something about them: a mere list has no such character" (Ghiselin 1997, p. 301) and "a good classification provides a system which has high predictive value and will allow maximum information retrieval" (Mayr 1969). "The ability to order and represent differences has aided the philosophical and scientific studies of biological, social, economic and technological entities, but it is important to recognize that the cognitive models produced by any classification are like the classifications themselves, incomplete, parsimonious and constantly evolving" (McCarthy 2005).

Cladistics will be applied in this work package to produce the final classification of the manufacturing models. The cladistical approach to formulating a classification system entails a study of the evolutionary relationships which occur amongst entities with particular reference to the group’s common ancestry. Any classification which is derived from an evolutionary relationship is deemed as being beneficial to the system as the classification will be both unique and unambiguous. The use of cladistics satisfies both of these criteria as the entities making up the classification tend to resemble each other in regards to both defining and non-defining characters. Cladistics is also viewed as being objective as it represents the unambiguous and natural property of the entity and as such different individuals, working independently of each other should be able to agree on a classification. The strength of the cladistical approach lies in its representation of the classification as the cladogram helps in illustrating the analysed data and results thereby making all decisions transparent. The cladogram is a tree-structure that can be used to represent the history of evolution of a group of manufacturing systems. The stages in carrying out cladistics analysis, including building a cladogram, will follow the approach described by, for instance, McCarthy and Ridgway (2000), Fernandez and McCarthy (2002) and Rakotobe-Joel *et al*. (2002). The cladogram of manufacturing model patterns will show how a problem may evolve over time along with the evolution of the systems. Two important elements to be investigated in great detail in this work package are the *heredity* and *speciation*. The former determines the genetic factors inherited to become the latter. In this way, a new species of simulation model can be constructed from a collection of the ancestor's characteristics based upon the history of the evolution. At this stage of the project the derived classification is reviewed and once no changes are needed, final approval is given. Only after settling on a final classification can the project proceed to the WP4.

3.5.4 WP 4: Develop A Prototype of A Rapid Model Generator

In order to evaluate the effectiveness of the proposed conceptual solutions, a prototype of a rapid model generator will be delivered in this work package. As it is intended to be a proof of concept, the prototype will be developed using a commercially available discrete-event simulation tool. The first stage in this work package will be to convert the model pattern in the form of *cladogram* into a model library, from which collections of model components will be retrieved and customised further to suit the need of the modellers. The model library represents archetypal manufacturing systems (and their associated problems) that exist within the SMEs under study. It is envisage at this stage that the library be implemented in a relational database system to which the prototype of rapid model generator can be directly linked. In forming such a library the individual components each become "building blocks" or "module" upon which the model can be developed. As the secondary user interface developed may be used to drive the simulation engine it can be described as a model constructor and as such it can be used to generate a simulation model.

The use of an external interface and the neutrally developed templates allows the modeller to create a simulation model that fulfils all the necessary requirements laid out in the commercial simulation package. The development of template based libraries help "simplify the model building process and also enables component based modelling, model reuse, and internet-based services, all of which could reduce the complexity and effort of simulation in manufacturing" (Son et al., 2000). A simulation model can be assembled by retrieving components from the model library through various access routes, such as type of manufacturing systems' (e.g. job shop, cellular, continuous flow) or through 'the problems they wish to tackle' (e.g. scheduling, optimising work-in progress). Once a template is built automatically, simulation parameters can now be entered into the model and experiments can be designed accordingly. It is envisaged that an external based user interface could be developed that would allow the smooth data transfer between the user interface and the simulation software package used.

This data transfer could be done through the use of visual basic scripting. Visual Basic Scripting (VBS) is a scripting language which has been developed by Microsoft and which has been modeled on its more widely known counterpart Visual Basic. VBS has been developed in order to facilitate a language which fosters fast interpretations for persons working in the Microsoft office environment and it use the Component Object Model to gain access to elements within the environment it is being used. An e.g. of this would be the File System Object (FSO) which is used to create, read, update and delete files. Whenever necessary, slight modifications to the logic may be applied to the template, which can further be saved in the library as a new variant of the model template. In order to ensure that the overall process is manageable, the development of the prototype will follow the *incremental* method, meaning that the final prototype is a result of an incremental development of a number of smaller prototypes through several *coding-testing* cycles. In the context of this research, the cycle is known as verification, ensuring that simulation models developed using the prototype produce the intended outcomes.

3.5.5 WP 5: Evaluate the Prototype and Confirmatory Study

The purpose of this work package is twofold: a) to validate the models developed using the prototype and therefore (b) to investigate that the aim and objectives have been achieved. It should be borne in mind that in any simulation study, model validations do not intend to prove that a valid model is the one that behaves like the real system. Rather, dependent upon a particular goal and hence a set of assumptions, it can be decided whether a model is valid or not. In this work package, validation will be carried out using the *walk-through* (expert judgment) method, where the models produced in the prototype will be tested for different goals using different assumptions. Companies who participated during the survey in WP 2 will be revisited to validate the prototype.

The confirmatory study will be carried out through a questionnaire followed up by a user group workshop. The workshop intends to strengthen the outcomes of the questionnaire-based evaluation. Once again, SMEs in the manufacturing sector who participated in this research project will be invited to attend the workshop. At this stage, the prototype will be hosted at Cranfield University and will be available for trial. This detailed study will therefore aim to identify a set of enablers and inhibitors of the new approach. Participants in the workshop will be asked to use the prototype so that their perceptions of ease of use, user friendliness and usefulness of the prototype can be captured.

3.5.6 WP 6: Prepare For Delivery and Dissemination

The purpose of this last work package is to ensure that the findings give a positive impact upon the better uptake of simulation and modelling techniques within the UK-based manufacturing industry. As discussed later in this proposal, a number of dissemination processes will be employed. The main mechanism will be by making the prototype available to a wider user, for example through the Manufacturing Advisory Services (MAS). Prior to that, the prototype will need final testing and refinement. The research methodology proces is depicted in figure 4 below.

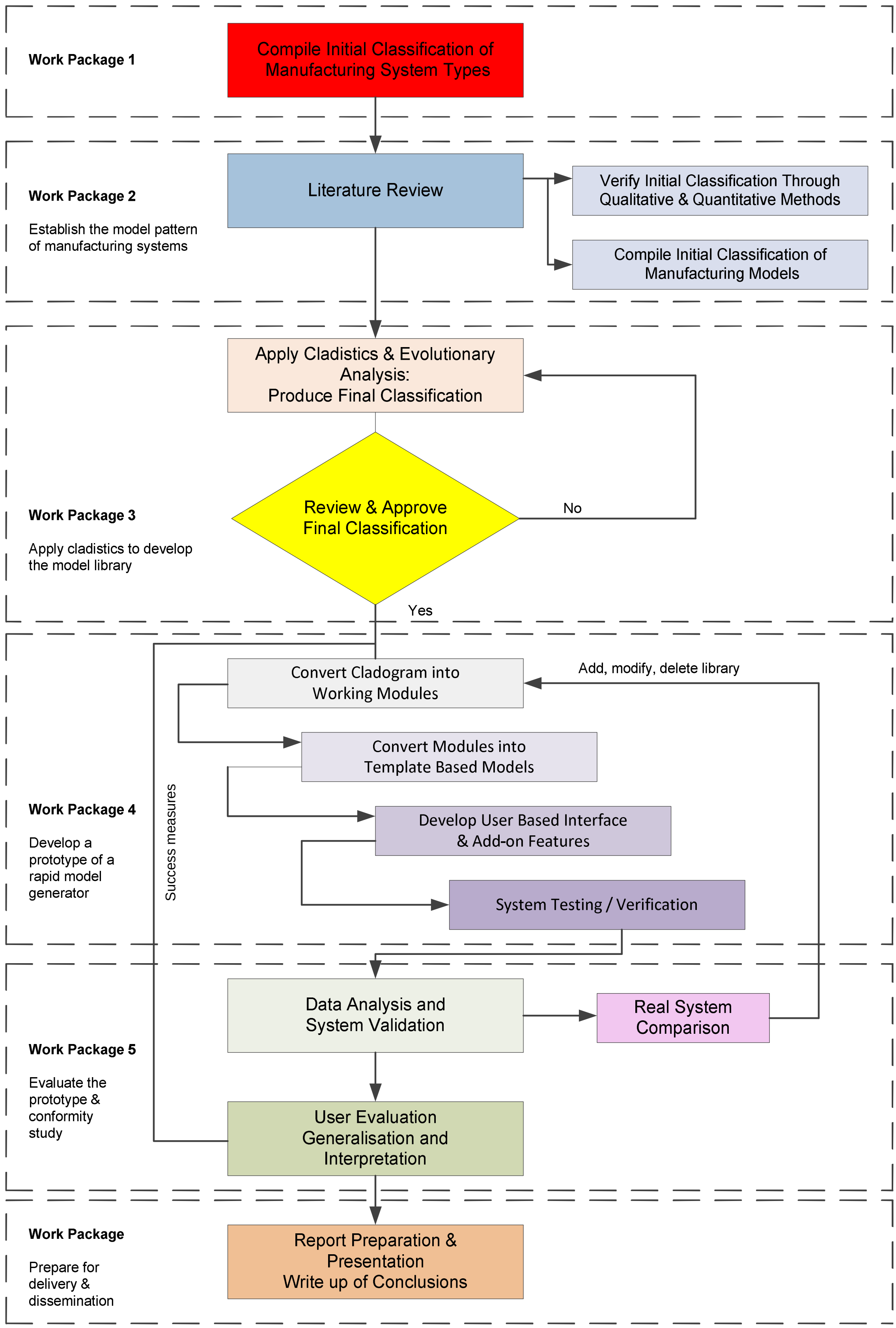


Figure 4: The Research Methodology

3.6 Research Deliverables

There are four principal deliverables that will be disseminated and exploited through a number of routes.

1) The knowledge of simulation model patterns that exist within the manufacturing sector.

2) A classification system for manufacturing layout types based on cladistics. This enables a novel and innovative way of rapid model conceptualisation and assembly and will be a valuable contribution to the simulation (OR) community.

3) A prototype of the rapid model generator (RapidSim). In order to promote the simulation techniques to the UK manufacturing industry and manufacturing SMEs in particular, it is proposed that open days will be held to further disseminate the research outcomes and increase awareness of simulation techniques..

4) A series of validation experiments to determine the value and possible contributions of the RapidSim modelling approach

3.7 Summary

This chapter details the research strategy which has been adopted for this research. The research carried out is a deductive one that employs the tools of experimental setup and retrospective studies to gather empirical evidence. The choice of research methods chosen implies that no causality between the independent variables and dependent variable can be ascertained. Causality can only be ascertained through true experiments and quasi experiments. This chapter has also outlined the scope of the research as well as the methodology and the work package guidelines which will be followed in the development of this research.

Chapter 4

Establishing the Model Pattern of Manufacturing Systems

4 ESTABLISHING THE MODEL PATTERN OF MANUFACTURING SYSTEMS

4.1 Introduction

At this stage of the research the purpose of this work presented is to aid in establishing a thorough understanding of the diversity and types of manufacturing system layouts that exist. The main aim at this time is the collection of information on the different types of manufacturing system models, based on the nature of their manufacturing processes, their typical layouts, material flows, routing logic etc., and to categorize this information into a classification system. The way in which this information will be collected is through a review of previous research and literature from various sources, predominately from journals and conference proceedings in the area of simulation and modelling. At this stage of the research, the main deliverable is an initial compilation and classification of manufacturing systems layouts.

The main objectives that need to be fulfilled in order to achieve these aims are as follows;

- To profile manufacturing systems that use simulation in order to develop a template based modelling library.
- To promote some understanding of the diversity and types of manufacturing systems.
- The collection and compilation of an initial classification of manufacturing systems models.
- The reclassification of these systems based on their similarity of physical layout.

The formulation of this classification system will be used a reference upon which the foundation of the next chapter will be based.

4.2 Compilation of Manufacturing System Types

The literature review of the information gathered allowed us to identify the various manufacturing systems which all use simulation at one time or the other as a decision making tool. These systems have been compiled and classified according to the type of production they employ and they will be presented in this section. At this stage of the research the author identified eleven (11) different manufacturing systems which are thought to be the most commonly used layout types in the manufacturing sector. The layouts identified are as follows; Fixed position layout, Job shop, Cellular manufacturing, Flexible manufacturing systems, Reconfigurable manufacturing systems, Transfer line, Flexible transfer line, Single model assembly line, Batch model assembly line, Mixed model assembly line and Spine. The layouts identified will all be discussed in greater detail in section 4.4 of this report.

4.3 Layout Types

4.3.1 <u>Fixed Position</u>

This is a layout type which is used when the products being manufactured are just too heavy, too fragile or too bulky to move to a plant or factory. The transformed parts or products do not move between stations or resources but instead the materials, equipment, information and personnel are brought to the product, at the production site and the product being manufactured remains stationary throughout its entire manufacturing life cycle (Slack et al 2007). During this type of production equipment utilization tends to very low, but considered negligible in monetary terms as it is more cost efficient to leave unused machinery on the production site rather than hauling it back and forth, increasing its cost to the operation (Russell & Taylor 2003). The workforce employed in this type of production tends to be highly skilled and this layout tends to be customized to meet the needs of the project it is being used for. Some examples of the products which benefit from this type of layout are;

- Motorway Construction
- Shipbuilding

- Mainframe Computer maintenance
- Construction Site
- Hospitals

In this system there exists a high degree of customization as products are built to customer specifications (Slack et al 2004). The part or product variety tends to be very low and the level of automation involved is minimal, work is carried out on a continuous basis and tends to get completed in sections at a time. As a result of this, fixed layouts tend not to have buffers or conveyors but instead are made up of machines and a high worker or labour concentration. However it should be noted that in practice the effectiveness of this layout type depends on the scheduling of access and deliveries to the main work site (Slack et al 2004).

4.3.2 Job Shop

Job shops as the name suggests are typically small based manufacturing operations dedicated to the handling of specialized manufacturing processes, based on small batch or small customer orders. Job shops function by processing one job at a time before they can move onto the next one, and there exist the possibility that most jobs tend to be based on different customers. In the context of a manufacturing operation we see that with the high level of specialization involved in the manufacturer of parts, there exists a high level of worker skill (Ostwald & Munzo 1997). Job shops can process a wide variety of products ranging from the simplest of components to the most complex which may require varied workstations and sequences of operations. Products produced by this method can have machining and handling routes which vary from one product to the other with no dominant flow pattern being readily visible. "An important characteristic of a job shop is the variability in job demand and a constantly changing product mix; therefore it is necessary for the system to be inherently flexible". (Montreuil et al 1999).

A typical example of a job shop would be that of a traditional machine shop, where items are manufactured in low quantities but for a very specialized market for e.g. the manufacturer of components for the aviation industry as opposed to the manufacturer of digital radios. In a job shop there exist relatively low levels of automation as most parts are produced from a skills base, however we should note that this high skill base accounts for a high level in the part variety which can be manufactured (Hitomi 1996). Most if not all job shops have a low number of machine workstations and they tend to be labour driven. As only one job is processed at a time and the parts are moved from one station to the other only after completing the previous operation, there tends to be no usage of buffering or conveying systems in this type of production system. In the context of a simulation model, job shops are easy to model but they are hard to tune and define as they lack some core elements needed for the simulation of the system.

4.3.3 Cellular Manufacturing

"The definition of a cell usually includes material handling or transfer capability. Robots are used to facilitate the movement of the product in combination with the human operator for loading and unloading the machines" (Farahmand 2000). Cellular manufacturing systems (CMs) are a manufacturing application of the group technology philosophy "which seeks to take full advantage of the similarity between parts, through standardisation and common processing. In this type of layout the machines are grouped together based on the process requirements for a similar set of products or part families" (Castillo et al 1997). The processes are then grouped together using grouped technology, which identifies parts with similar design and process characteristics.

The major advantage to the use of grouped technology is that there is a significant improvement in the material flow, which in turn reduces the material travel distance, the levels of inventory needed and the cumulative lead times. "The basic grouping of machines and parts are based on a binary machine-part incidence matrix that shows the occurrence of visits made by parts to machines" (Roa et al 2006). Cellular production is used in most instances to arrange the labour which is used on the factory floor into teams of semi-autonomous and multi-skilled workers or work cells who are capable of producing either completed products or complex parts or components. Cells which are made up of properly trained workers and which has been properly implemented tend to be more flexible and responsive than the traditional mass production lines and can manage processes, defects, scheduling, equipment maintenance, and other manufacturing issues more efficiently. The overall goal of any cellular manufacturing system is to enable the system to with the necessary degree of flexibility which is needed in order to produce a wide variety of low demand products whilst still maintaining high levels of productivity needed for large scale production. Simulation is used to facilitate design and redesign of these groupings so as to achieve the desired outcomes. In a cellular system parts are firstly pulled from the external environment into the cell via the use of a conveyor or a manual transport device and then pushed throughout the cell until the finished product is obtained. The cellular layout can be further decomposed into its three core groups as shown in figure 5 below, they being machine + operator, machine + conveyor or machine + robots, or any combination of the three, each with their operational advantages and problems (Maas and Standridge 2005).

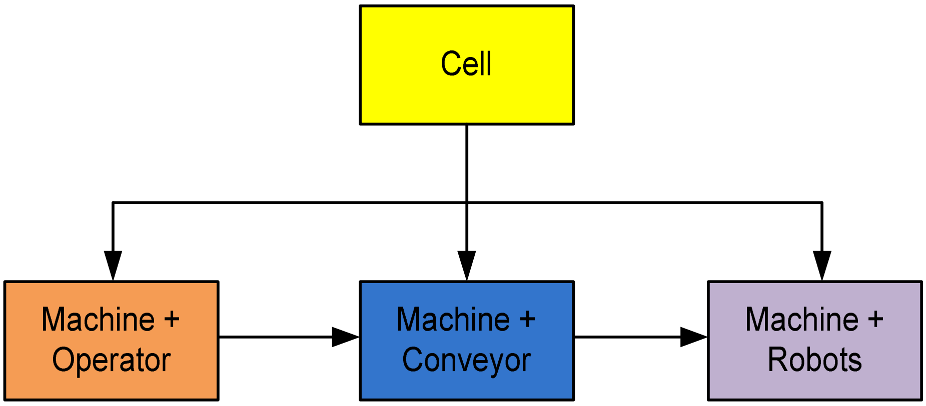


Figure 5: The Typical Cellular Configuration

4.3.4 <u>Flexible Manufacturing Systems</u>

"Flexible manufacturing is one of the key issues for manufacturing industries in order to survive the severe competition in recent years" (Kidd 1995). The rapidly changing patterns of market demands for goods and services require manufacturing systems which are able to adapt in order to produce a wide variety of products accompanied by varying volume levels. "Flexibility can be viewed as the capacity of a system to change and assume different positions or states in response to changing requirements with little penalty in time, effort, cost, or performance" (Toni and Tonchia, 1998). A flexible manufacturing system (FMS) is a system where there is some degree of flexibility within the production process that allows the system to react to changes, whether they be predicted or unpredicted. "Flexible Manufacturing Systems consists of numerous programmable machine tools connected by an automated material handling system and controlled by a common computer network" (Russell & Taylor 2003).

Flexible manufacturing systems (FMS) are capable of manufacturing a wide variety of products due to their high flexibility through the use of machines for e.g. CNC’s and robots which may be fitted with a wide variety of tooling allowing them to perform a variety of operations. FMSs consist of processing stations and material handling systems that are entirely under computer control (CNC, DNC). This can be depicted in a simulation environment through the use of machines and conveyors based on a push system, as there exist a high level of automation no buffers or operators are used. Over the years at least 10 types of manufacturing systems flexibilities have been identified, they being; "Machine flexibility, Material handling flexibility, Operation Flexibility, Process Flexibility, Product Flexibility, Routing Flexibility, Volume Flexibility, Control Program Flexibility, and Production Flexibility" (Sethi and Sethi, 1990). Although they are depicted as being separate entities, there is some degree of interaction between the different groups.

4.3.5 Reconfigurable Manufacturing Systems

"There is a need for a complete reconfigurable modular manufacturing system which can be easily adapted to product changes and demands and which can compete on a cost basis with the labour flexibility used in low cost countries" (Johansson et al 2004). One such system which can deliver this type of flexibility is that of the RMS. "A reconfigurable manufacturing system (RMS) is one designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality within a part family in response to sudden market changes or intrinsic system change" (Koren et al 1999). Reconfigurable Manufacturing Systems (RMSs) were first introduced in the mid-nineties as a cost-effective response to the shift in market trends from one of mass production to one of mass customization (Abdi & Labib 2004). (RMSs) aimed at achieving cost-effective and rapid system changes, as and when needed. "An ideal Reconfigurable Manufacturing Systems possess six core RMS characteristics they being; Modularity, Integrability, Customized flexibility, Scalability, Convertibility, and Diagnosability" (Koren & Ulsoy 2002).

These key principles are emphasized as prerequisites to enable (RMSs) to work as intended and achieve the desired reduction in time and cost (ElMaraghy H.A 2005). One of the greatest advantages of this type of production system is its ability to deliver customized flexibility on demand in a shorter time frame, as compared to Flexible Manufacturing Systems (FMSs) which provide generalized flexibility that is designed into the system in anticipation of variations in the production process. (RMSs) are based on a high level of automation and flexibility and as a result their makeup tends to be one of machines and conveyors and productions are facilitated by both push and pull factors within the system.

4.3.6 Transfer Line

Transfer lines have been seen as the tools of mass production over the last 30 years with main emphasis on their usage within the automobile industry. The machines used in this type of production have traditionally been highly inflexible, but with advances in technology we see that there is movement towards a line with a higher level of flexibility. An e.g. of this “hybrid” transfer line are two lines designed by Cross for BMW to machine V6 and V8 blocks. "Machines in a Transfer Line could be a single spindle grinding machine or a 30 station transfer machine" (Ladbrook 1998). "Operations performed by these machines vary from milling faces, drilling and tapping bolt holes to finish honing various bores. The number of machines in the process varies, dependent on the type of component being manufactured and the volume required" (Ladbrook 2001). In a transfer line the part is firstly fixed to a workstation where all the operations or blocks are performed in a sequential manner. All operations are performed simultaneously by one piece of machinery, and only when all operations are performed block by block and in a sequential manner then the part is moved along the line to the other workstation and the cycle of machining for this workstation is terminated. Workstations are visited in order of their index. In transfer lines (TL) buffers exist between stations and the line cycle time is constrained by the bottleneck workstation. The limitation of transfer lines however lies in their rigidity and devotion to one, or a closely-knit, small, like family of components. The make-up of these systems is highly automated and they consist of machines + buffers + conveyors.

4.3.7 Flexible Transfer Line

Flexible transfer lines are similar to traditional transfer lines with the biggest difference them being their varying degree of flexibility. Traditional transfer lines are highly inflexible while the more modern flexible transfer lines tend to have a high degree of flexibility built into the system. The flexible transfer line (FTL) is now used widely in many manufacturing domains to realize efficiently, high quantity and economic production. These manufacturing domains include automobiles, tractors and internal-combustion enginesto name a few. In today’s competitive business environment, it is vitally important for machine tool manufacturers to design FTLs more effectively and efficiently according to a wider variety of customer demands. Companies who wish to remain successful must be able to quickly adapt to the fast changing conditions of the marketplace and to changes made by their competitors in terms of shorter lead times and lower cost

4.3.8 Single Model Assembly Line

Assembly lines are designed for the sole purpose of exploiting the sequential organization of workers, tools or machines, and parts with worker motion minimized to the greatest extent possible. In assembly line manufacturing, interchangeable parts are added to the production process through the use of logistical control in an orderly manner to create a finished product at a much faster rate than through the use of a handcrafting type method. An assembly line is typically a flow orientated system where the workstations are aligned in a serial layout. In an assembly line all parts or assemblies are handled either by conveyors or motorized vehicles such as forklifts or AGV’s, or gravity and there is no manual transportation involved in the movement of parts between workstations. Heavy lifting is done either by machines such as overhead cranes or forklifts with each worker performing one simple dedicated operation. Assembly lines were originally developed as a cost efficent approach to the mass production of goods and standardized products. They were designed from the beginning to exploit the high specialization of labour and leaning effects associated with carrying out repetitive tasks.

One of the earliest assembly lines created was set up by Henry Ford to commercialise the mass production of their famous model-T however, it should be noted that "product requirements and thereby the requirements of production systems have changed over the years" (Umble et al 2000). According to (Ford, H 1922) "the principles of assembly" are these:

- "Place the tools and the men in the sequence of the operation so that each component part shall travel the least possible distance while in the process of finishing".
- "Use work slides or some other form of carrier so that when a workman completes his operation, he drops the part always in the same place--which place must always be the most convenient place to his hand--and if possible have gravity carry the part to the next workman for his operation".
- "Use sliding assembling lines by which the parts to be assembled are delivered at convenient distances".

In an assembly line process the work pieces visit the workstations successively as they are moved along the line through the use of a transportation system for e.g. that of a conveyor belt. "The use of Multi-purpose machines with automated tool swaps allow for facultative production sequences of varying models at negligible setup costs. This makes efficient flowline systems available for low volume assembly to- order production" (Mather, 1989).

4.3.9 Batch Model Assembly Line

In a Batch model assembly line system, the systems are designed with the aim of producing two or more models on the same assembly line. In a batch assembly system each model is produced according to the specified batch quantity, with workstations being set up to produce the first model and then subsequently reconfigured to produce the next model and so on. With reference to the workstations "set up" we are referring to the assignment of tasks at each station of the line, including the special tools needed to perform the tasks and the physical layout of the stations (Groover 2008). Batch model assembly systems can cater for a wider degree of product variation than that a single model assembly line and they usually have some degree of flexibility built into the system as opposed to the highly inflexible single model systems. These flexibilities can take the form of either machine flexibility, product flexibility or production flexibility or they can be a combination of all the above.

Models which are usually produced using this production system tend to come from a similar or grouped part family and therefore the tasks needed to make them are also similar. However as no two models are alike there are some differences which need to be taken into consideration in this type of production system. The sequence of tasks and the tooling may vary for each model produced and as a result one model may take more total time to produce than another, resulting in the line having to be operated at a slower pace (Groover 2008). As machine and tools may need to be changed during the station set up before production of the next model can begin it should be noted that these changeovers result in loss production times on batch model assembly systems.

4.3.10 Mixed Model Assembly Line

In a mixed model assembly system more than model is produced at the same time. However, models are not made in batches but they are instead made simultaneously on the same line. While one station is busy working one model type another station is busy processing a different model (Groover 2008). In mixed model systems each workstation is equipped with a wide variety of tooling, jigs and fixtures and material handling devices in order to perform the necessary tasks which are needed to produce any given model that moves through that station. Mixed model systems do not need nor do they rely on machine changeover at stations. Since each workstation is multifunctional i.e. equipped with all the necessary tools and fixtures in order to produce any given production model there tends to be no loos in production time when changing between models.

Mixed model systems also have the ability to change production rates to suit demand patterns. This type of “system scalability” enables producers to adapt to the changing patterns of consumer demands for any given model which is made on the line. These production systems also benefit from the use of skilled labour as workers become more adapt at producing a wider variety of models. An example of a mixed model system is that of an automobile company where models demanded from the customers have different colours, different transmissions, i.e. automatic transmission or manual transmissions and varying styles of interiors (Groover, 2001). It should be noted however that in these systems the throughput of one area affects the throughput of another. For example in an automobile assembly plant using a mixed model system a problem which occurs in the paint shop could starve the assembly shop and in turn cause a blockage or bottleneck in the paint shop (Park et al 1998).

4.3.11 Spine

Spine layouts are a new concept of manufacturing which layouts which have the hybrid features of both a flow line and a multiple autonomous cells. In the spine layout the product moves along a main artery, or spine, through the plant. "Linked to the spine are mini-assembly lines owned by the suppliers, each attaching its own module to the moving product with the layout adopting the hybrid features of both a flow line and multiple autonomous cells. The configuration allows the addition and removal of suppliers without affecting the main layout and it also accommodates gracefully both growth and contraction of supplier operations" (Benjafaar et al 2000)**.** This layout type is based on the arrangement of the production or part flow and it allows for some portions of the facility have a flexible-flow and others have a line-flow layout. The reduction in setup time and cost of work in progress coupled with the reduction in flowtime and inventory are some of the key advantages of a hybrid system.

In many industries, outside suppliers are increasingly carrying out most of product manufacturing and assembly for the original equipment manufacturers. Coupled with just-in-time deliveries, this has led to a reconfiguration of final assembly facilities to accommodate the closer coupling between suppliers and OEM’s (Gibson P 2000). The most common uses of a spin layout can be found in automotive manufacture. There is now an emerging trend where manufactures allow their supplier to deliver parts directly the point-of-use on the final assembly line. A good example is the new Cadillac plant in Lansing, Michigan which has been T-shaped to maximize supplier access to the factory floor (Green 2000). One of the best examples of a spine layout which is being used in automotive manufacture is the GM Gravatai plant in Brazil. This plant houses a final assembly plant and 16 supplier plants, including plants owned by Delphi, Lear, and Goodyear. "Their job is to deliver pre-assembled modules to GM's line workers, who then piece the cars together in record time. The 17 plants are within walking distance from each other and are connected through a shared material handling system of forklift trucks and conveyors" (Benjafaar et al 2000)**.**

4.4 Simulation Model Development

4.4.1 <u>Modelling and Simulation</u>

Simulation models have become more prevalent in both the business and industrial sectors thus making the use of simulation not as alien a concept as one would have thought. For example when weather forecasters on the television show us predictions of weather fronts for the upcoming days, detailing their movement they are in fact showing us a theorised simulation model. Another example which is more prevalent and which we can all relate to is the use of gaming consoles. Consoles are able to simulate a wide variety of different scenarios allowing the user to test their skills as race car drivers, boxers, athletes etc. The use of simulation for these purposes needs to be entirely computer based, however there are some instances where the simulation model in question may be entirely physical based. Model railways and remote control boats are familiar examples of physical simulations. So what do users and designers mean when they refer to the term simulation? The most commonly used definition of simulation, defines simulation as “An imitation of a system”. However for the purpose of this research the focus is on computer based rather than physical based simulations. Building on the previous definition, computer based dynamic simulation can be defined as follows: “*An imitation (on a computer) of a system as it progresses through time*” (Robinson, 2004).

In today’s fast paced and highly industrialised society the use of simulation, simulation based technologies and modelling are becoming an important and indispensable factor in the way manufacturing companies are able to remain competitive in the global market place. Greater technological and industrial advances in both the manufacturing and business sectors respectively have led to a work culture which facilitates the need for and the adoption of, simplified work techniques which are both user friendly and cost effective. In a world where mistakes can prove to be too expensive, modelling and simulation provides the managers an alternative. “A simulation model is a device on which dynamic experiments can be conducted” (Robinson et al., 2004). "In M&S, the users are provided with a world that is away from reality, wherein ideas can be tried out, either to succeed or to fail. Any mistakes made, or pitfalls one can fall into in such a world becomes a learning process that cost next to nothing. Thus, risks can be analysed and alternatives tested out in a hassle free world. The final decision-making thus becomes easier and are based on tried out alternatives" (Suggs and Lewis, 2007).

A study conducted by Integrated Manufacturing Technology Road mapping (IMTR) Project Team concluded that “Modelling and Simulation are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more than a fraction of the potential that M&S does for improving products, perfecting processes, reducing design-to manufacturing cycle time, and reducing product realisation costs” (McLean and Leong, 2001). Thus it is imperative that the modelling and simulation is made easily available and made user friendly to enhance its applications in all the operations.

4.4.2 The Need For Simulation

In order to discuss the need for simulation in the workplace there are a few concepts which need to be understood before the need for simulation can be addressed. First on the list is the need for variability. This is the need to predict variations which may occur in the day to day operational requirements of the organization. A good example of predictive variation is in call centres, where depending on the call volume the number of operators may need to be changed during the course of the day in order to meet the fluctuating pattern of demand. Secondly is the concept of interconnectivity. Most operation systems are interconnected with the components used in the system not isolated from each other but interconnected with their performance affecting one another. Changes which occur in one part of the system can lead to changes in other parts of the system. An example of where this can occur is when one machine is set to work faster than the others. This scenario can lead to a reduction of the work in progress upstream while at the same time leading to a build up of parts downstream.

However it should be noted that there exists a degree of difficulty in predicting the effects of interconnectivity on any system, with the level of difficulty increasing as the level of variability increases. The third and final aspect of simulation which needs to be understood is that of complexity. In regard to simulation modelling there are two main types of complexity which needs to be taken into account for any system they being combinatorial complexity and dynamic complexity. As the name suggests, combinatorial complexity can relate to the number of components which are present in the system or it can be relate to the combination of all the system components which may be possible. Combinatorial complexity can be present in some systems but not in all. A good example of where this type of complexity occurs in a traditional job shop environment where as the “n” umber of machines increase so does the potential level of interconnections. Dynamic complexity however is not related to size and it occurs due to the interactions between system components over a given time period. This type of complexity can occur in small as well as large systems and systems which possess a high level of interconnections are most likely to display this type of complexity.

"Most operations systems are interconnected and subject to both variability and complexity (combinatorial and dynamic)" (Robinson 2004). As it is extremely difficult to predict the performance of any given system which is subjected to one of the following; variability, interconnectivity and complexity it is even near on impossible to predict the performance of these systems when all three of these conditions exist. This however, is not the case with simulation. Simulation models are able to take into account any or all three conditions and as a result simulation can be used to accurately "predict the system performance, to compare alternative system designs and to determine the effects of alternative policies on system performance". Also the combination of modelling variability and interconnectedness means that complexity in a system can be represented by a simulation model.

4.4.3 The Conceptual Model

According to Law (1991) "Conceptual modelling is almost certainly the most important aspect of the simulation modelling process". Most simulation users are of the view that by simply completing the conceptual modelling exercise 50% of the benefits can be obtained from the simulation study. In order to develop a great understanding of the model to be developed, the modeller needs to develop a more thorough understanding of the operational system which is in use. By asking questions and seeking answers the modeller considers all forms of information on the system to be modelled, which in turns leads to the design of the simulation model becoming a framework for system investigation. Shannon (1975) goes so far as to say that "effective conceptual modelling may lead to the identification of a suitable solution without the need for any further simulation work". Robinson (2004) defines the conceptual simulation model as "a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model". It should also be noted that a well-designed conceptual model will increase the chances of the proposed simulation study meeting its objectives within the given time frame.

When designing a conceptual model it is always handy to have a set of specific requirements in mind, thus enabling the model to be designed to meet the needs of those requirements. According to Robinson (2004) there are four basic requirements for any conceptual model which are not mutually exclusive;

Validity: A valid model is one that is sufficiently accurate for the system it needs to model. This is based on the perception that the conceptual model will lead to the production of a credible and accurate computer based simulation model.

Credibility: This is taken from the client's point of view as opposed to the person modelling the system. Again this is based on the perception that the conceptual model will lead to the production of a credible and accurate computer based simulation model.

Utility: This can be seen as a joint agreement between the client and the modeller about the usefulness of the model. This is based on the perception that the conceptual model will lead to the production of a credible and accurate computer based simulation model which can aid in the decision making process.

Feasibility: This is based on the perceptions of both the client and the modeller that the conceptual model can be developed into a credible and accurate computer based simulation model.

The conceptual model can be represented by using one or more of the following tools;

- A component list
- A process flow diagram
- A logic flow diagram
- An activity cycle diagram.

To aid in the development of a conceptual model for this study a logic flow diagram was chosen to best represent the informational requirements for the simulation model. The logic flow diagram is used to illustrate the logic flow of the information as opposed to the process flow. Analysis of the data collected form the literature review process led to the development of the logic flow diagram. The data collected identified the manufacturing system types as well as the layout type components and it helped provide structure to the template based model library. The structure of the logic flow diagram came about as a direct corelation between the information gathered from the literature review and the authors perception of how the template based library should operate. The authour identified how similar template based libraries were constructed in the review, and used this as a guideline to develop the logic flow process for this library.

At each stage opf the process the logic that went into building the model was tested against how the model was acutally built and any changes needed to the model or the logic flow were made. This process ebnabled the author to follow a structured methodology for creating a model template that was truly reflective of the logic requirements of the model. As the modules that were used to bulild the the model were generic in nature, following this process enabled the end user to modify the component to their specific requirements.

It should be noted that as the template library constructed was to be used in not one but many manufacturing systems there were no alternative logic flow processes which the author could follow. Previous research into template and model building focused only on one manufacturing system at a time.

Figure 6 shows the logic diagram used to aid in developing the conceptual template based model library.

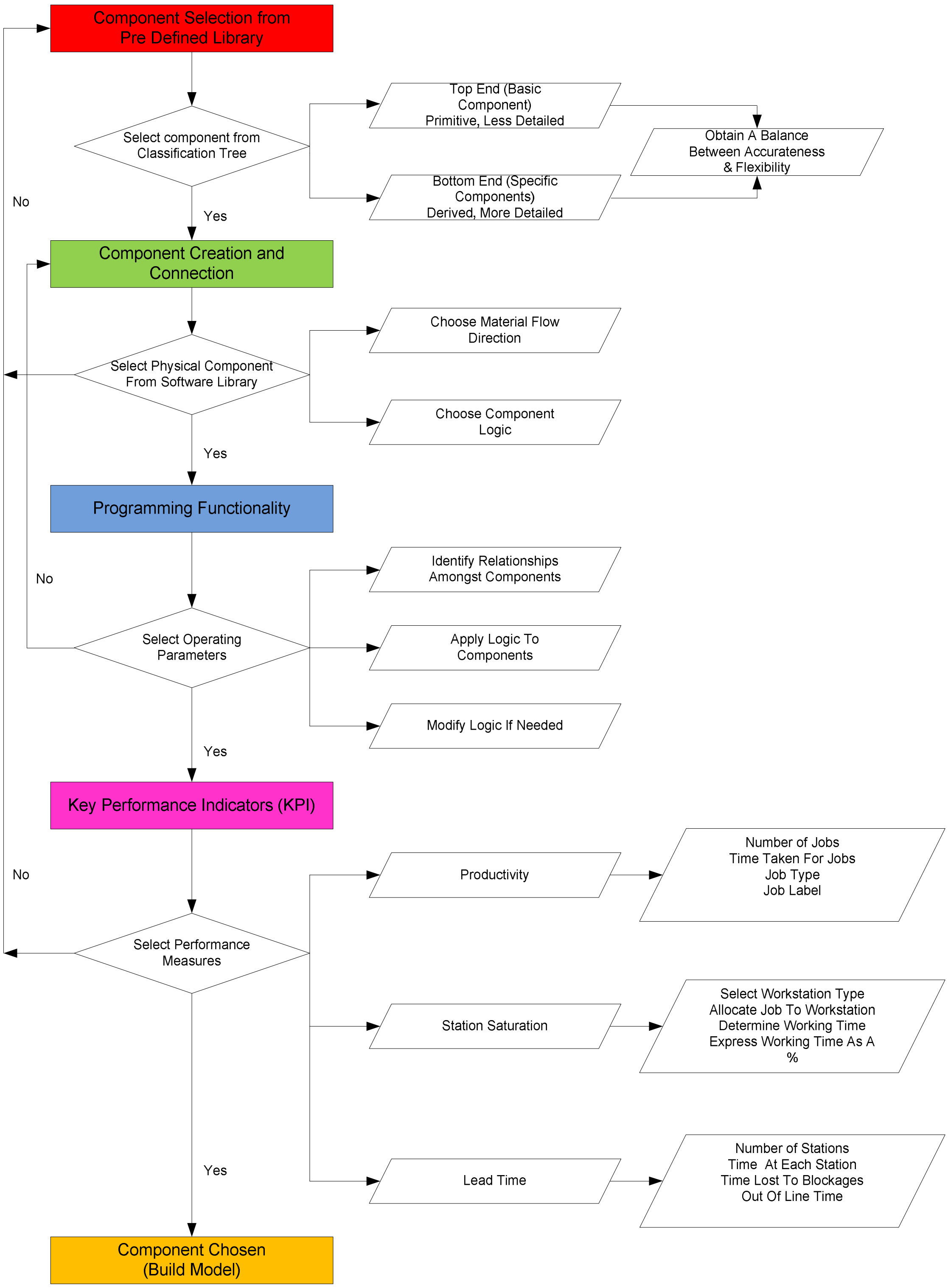


Figure 6: The conceptual template based library

4.5 Classification of Manufacturing System Types

After research and analysis into the different manufacturing systems types identified in the review, an attempt has been made to identify the commonalities and differences which some of these systems may possess and to display this data in the form of a classification system. Review of the literature showed that although the use of machines, buffers, conveyors, workers and the quantity or volume of production were present in most of the systems identified these factors alone were not enough to formulate a classification. As the classification was based on the layout types identified from the literature review it was only fitting that the characteristics which make up these various layouts form the differentiating basis for the classification. The total number of characteristics identified came to 14 and included characteristics such as dedicated cells, product flexibility, sequential part movement and automatic machine changeovers but to name a few. In the classification depicted in table 4 below the vertical axis details the different types of physical layouts identified from the literature research process. A total of eleven (11) layouts were identified and these are as follows; job shop, cellular manufacturing, flexible manufacturing systems, reconfigurable manufacturing systems, transfer line, flexible transfer line, single model assembly line, batch model assembly line, mixed model assembly line and the spine layout.

To obtain answers to the characteristics chosen a yes or no answer system was used to identify if the characteristic existed in the physical layout, and the answers were depicted through the use of (✓) for yes and (✗) for no. This combination of answers formed the basis for the classification system. However, arriving at a classification system does not guarantee that the information provided in the diagram would be of any use unless the information presented here could be used in construction of the template based modelling library. The classification system depicted in Table 4 was used as the basis for the decision matrix for the RapidSim Interface. The yes and no answers provided were used as the basis for the programming logic for user selection of layout types, with the information presented in the classification forming the basis for the first three frames of the RapidSim Interface.

The classification arrived at by the author was checked to ascertain both its accuracy and its functionality. As the classification was used to program part of the user interface the information presented here was checked against the information gathered from the literature review in regard to the layout type characteristics and physical makeup. Although the classification was scheduled to be completed during the 3rd work package the author found that this was not possible as the classification needed to be continuously fine-tuned so as to give a true representation of the systems being classified. The information presented in the classification was checked and then double checked against both the manufacturing system type and the layout characteristics before the final classification was established and agreed to in work package 4.

Table 4: The System Classification

Conditions

Layout Type	Low Volume	Medium Volume	High Volume	Dedicated Cells	Process Flexibility	Expansion Flexibility	Production Flexibility	Product Flexibility	Has Customization	Has Scalability	Has Sequential Part Movement	More Than One Model Produced	Standardised Assembly Times	Automatic Machine Changeovers
Job Shop	✓	X	X	X	X	X	X	X	✓	X	X	✓	X	X
Cellular Manufacturing	X	✓	X	✓	X	X	✓	X	X	X	X	✓	X	X
Flexible Manufacturing System	X	✓	X	X	✓	✓	✓	✓	X	X	X	✓	X	X
Reconfigurable Manufacturing System	X	✓	X	X	X	X	✓	✓	✓	✓	X	✓	X	✓
Transfer Line	X	X	✓	X	X	X	X	X	X	X	✓	X	X	X
Flexible Transfer Line	X	X	✓	X	X	X	✓	✓	X	X	✓	✓	X	✓
Single Model Assembly Line	X	X	✓	X	X	X	X	X	X	X	✓	X	✓	X
Batch Model Assembly Line	X	X	✓	X	X	X	✓	✓	X	X	✓	✓	✓	X
Mixed Model Assembly Line	X	X	✓	X	X	X	✓	✓	✓	✓	✓	✓	✓	X
Spine	X	X	✓	X	X	✓	✓	✓	X	✓	X	✓	✓	X

4.6 Summary

The work carried out in this chapter focused on how a simulation model could be developed and how this information could be used in constructing the template based modelling library. Also a comparison was given between the conventional modelling approach and the proposed new RapidSim approach with the potential benefits of the new approach discussed. After reviewing the current literature available on the different layout types that exist a classification system was constructed that would be used to aid in the development of the template based model library. The scope of the work carried out in this chapter will form the basis of the next chapter as the layout types presented as well as their characteristics will be used to construct the cladogram of manufacturing system types, the template based modules and the modelling library.

Chapter 5

Using Cladistics to Develop a Model Library

5 USING CLADISITICS TO DEVELOP A MODEL LIBRARY

5.1 Introduction

A classification "arranges materials in a way that tells us something about them: a mere list has no such character" (Ghiselin 1997, p. 301) "and a good classification provides a system which has high predictive value and will allow maximum information retrieval" (Mayr 1969). "The ability to order and represent differences has aided our philosophical and scientific studies of biological, social, economic and technological entities, but it is important to recognize that the cognitive models produced by any classification are like the classifications themselves, incomplete, parsimonious and constantly evolving" (McCarthy 2005). Within the biological sciences there exist two main schools of contention in regard to the principles of classification, these being phenetic or phylogentic principles respectively. From these two underlying principles three varying approaches to classification have been developed: phenetic, evolutionary and cladistic.

Cladistics is a purist approach to the phylogenetic principle and the evolutionary classifications developed tend to be a combination of the phenetic and phylogenetic principles. The end product of any cladistical analysis is the generation of a system cladogram. Cladograms can be described as tree like diagrams which display the relationship patterns which has been established amongst entities or clades as a result of their shared or derived characteristics. The limbs or branches of the tree diagram are used to represent the taxa while the tips of the branches are used to represent the species. Any classification which is derived from an evolutionary relationship is deemed as being beneficial to the system as the classification will be both unique and unambiguous. Manufacturing systems should be considered as a complex and organized evolving systems as they are always responding to chaotic changes in the marketplace. Being an organized system most manufacturing companies conform to the ways in which organizational systems exist and evolve.

The process of conducting, documenting and co-ordinating comparative studies which are based on manufacturing organizations could be feasible if a cladistical classification of these systems were in place. Any such system would provide the framework for formally approving any new manufacturing systems that emerge. Cladograms could be used to represent the changing nature of manufacturing systems over time and as such they can provide valuable knowledge and insight into the changing characteristics which are exhibited by manufacturing systems throughout the course of their development.

The work detailed in this chapter will look at how cladistics has evolved over time and how this concept has been put to use in the manufacturing industry. It will also focus on the cladogram building process, culminating in the design and analysis of the cladogram of manufacturing system types and simulation system components. The information obtained from the development of the cladogram in this chapter will be used in the following chapter to design the template based simulation modules.

5.2 Information on Cladistics

The human desire to classify objects and information transcends all boundaries and disciplines no matter if the entities under study are mechanical, biological or chemical elements. For the purpose of this research the focus would be on the classification of the various manufacturing system types which exist.

A noted mathematician of his day, Good (1965), provided a list which suggested five possible reasons why an individual or an organization would want to perform a classification exercise. They are as follows;

1) For mental clarification and communication;
2) For discovering new fields of research;
3) For planning an organisational structure or machine,
4) As a check list and
5) For fun.

Cormack's (1971) publication in the proceedings of the Royal Statistical Society summarised the benefits which could be obtained by adopting a hierarchical classification system, stating that "the information about the entities is represented in such a way that it will suggest fruitful hypotheses which cannot be true or false, probable or improbable, only profitable or unprofitable". McKelvey (1975) took this arguement further by stating that “the formulation of a classification system is a necessary prerequisite for the maturation of organisation science and that, if a formal and scientific classification existed, there would be no need for contingency theory”. Carper and Snizek (1980), in their review of organisational classifications concluded that "the most important step in conducting any form of scientific enquiry involves the ordering, classification, or other grouping of the objects or phenomena under investigation".

A classification "arranges materials in a way that tells us something about them: a mere list has no such character" (Ghiselin 1997, p. 301) "and a good classification provides a system which has high predictive value and will allow maximum information retrieval" (Mayr 1969). "The ability to order and represent differences has aided our philosophical and scientific studies of biological, social, economic and technological entities, but it is important to recognize that the cognitive models produced by any classification are like the classifications themselves, incomplete, parsimonious and constantly evolving" (McCarthy 2005). Schumacher & Czerwinski (1992) went on to state that "a classification should permit continuous development and refinement, whilst at the same time providing simple and powerful explanations of complex phenomena". The first formal sets of classifications were thought to have been produced by philosophers and biologists in order to make sense of the world around them. This combination of varying intellects aided in the development of a number of similar and competing theoretical and analytical stances on how information should be classified which in turn has led to the acceptance of classifications as an established research process in both the physical and social sciences.

Within the biological sciences there exist two main schools of contention in regard to the principles of classification, these being phenetic or phylogentic principles respectively (figure 7). From these two underlying principles three varying approaches to classification have been developed: phenetic, evolutionary and cladistic. Under the phenetic system of classification the entities to be studied are classified based on their overall or observable similarities whilst under phylogentic's they are classified on how closely they share a recent ancestor. With this in mind there are now three emergent schools of classification which are catogorized on how closely they support a purely phylogenetic principle. Phenetic classifications are always non evolutionary and as a result tend to be at one end of the evolutionary scale. Cladistics can be viewed as a traditionalist approach to phylogenetic principles and any classification which is derived from this approach tends to be a combination of both the phenetic and phylogenetic principles.

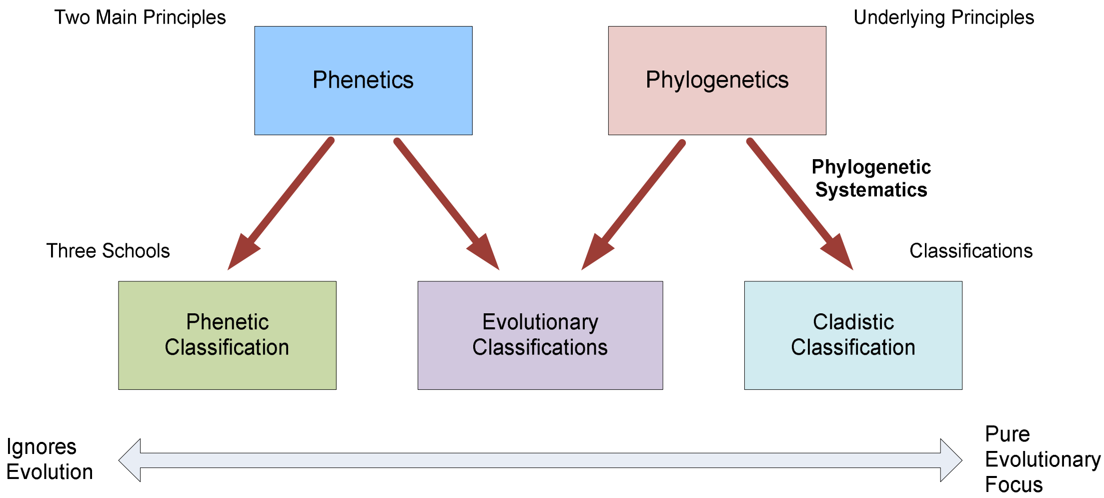


Figure 7: The biological schools of classification: Taken from McCarthy et al (2000)

The period between the 1930's and 1940's saw phenetics and numerical taxonomy taking prominence as the established school of classification as more and more biologists accepted Darwin's "theory of evolution" which resulted in a resurgence of evolutionary biology and systematics. During the same period however, an alternative school of classification started to take shape headed by the German entomologist Willi Hennig. Hennig (1950) believed that "evolutionary history should play a greater role in taxonomy and that biological classifications should only focus on one aspect of phylogeny", that being how recent, entities had shared a common ancestry. Hennig (1950) went on to further explain "that even if two taxa share a large number of homologies, their classification within the same group cannot be conclusively assumed, as homologies can result from shared derived characters or shared ancestral characters".

Henning's approach to classification was originally termed phylogenetic systematics but the name was later changed to cladistics from the Greek word Κλαδos meaning branch. As such cladistics is seen as being is approximately equal to phylogenetic systematics and originally meant the study of clades, which are "the individual branches in the genealogical nexus" (Ghiselin 1997). The end product of any cladistical analysis is the generation of a system cladogram.

5.3 Cladistics in Manufacturing

McCarthy (1995) discussed "the importance of formal and scientific classifications for understanding the diversity of manufacturing organizations and their defining characteristics whether they be technological, social, operational or structural". Cormack’s (1971) publication in the proceedings of the Royal Statistical Society summarised the benefits which could be obtained by adopting a hierarchical classification system, stating that "the information about the entities is represented in such a way that it will suggest fruitful hypotheses which cannot be true or false, probable or improbable, only profitable or unprofitable". Further support the need for a system which is based on organizational classification comes from Romanelli (1991), who states that "despite the ease with which we may identify meaningful groupings of organisations, no commonly accepted classification scheme has been developed".

In the words of Ridley (1993, p. 367): "Cladism is theoretically the best justified system of classification. It has a deep philosophic justification which phenetic and evolutionary classifications lack". Work carried out by Queiroz (1988) and later on by Wiley et al. (1991) focused on assessing the three schools of classification on their ability to produce natural and objective classifications as opposed to artificial and subjective classifications.

Like the evolutionary nature of the global marketplace, manufacturing companies and to a greater extent the industries they belong to are constantly evolving. Evolutionary changes result in irreversible changes to manufacturing systems as new and more efficient processes and technologies replace existent and redundant processes. Being an organized system most manufacturing companies conform to the ways in which organizational systems exist and evolve. In order for cladistics to be applied to evolutionary models which are not based on biological factors it is necessary to establish what evolution means to the entity under the proposed study. In this instance the entity under study will be manufacturing organizations and the environment it belongs to would be the industrial and economic ecosystem. As a cladogram is used to represent the evolutionary history of a particular group of manufacturing systems its branches illustrates the different manufacturing system types, the varying relationships between these different systems and the evolutionary path taken by each system. The evolutionary paths illustrated in the cladogram demonstrate the organizational changes which must be completed in order for one system to evolve into another. Each path is formed based on the acquisition and polarity of certain characters (manufacturing characteristics).

"Using a systematic and comparative method such as cladistics, permits an assessment of the generality of the attributes of complex systems" (Pinna, 1991). The desire to develop a theory of organizational differences as well as a valid cladistical classification could be a valuable tool in explaining the way in which manufacturing systems persist and exist over time, with particular reference to their practices and organizational structure. Cladograms can be used to give valuable insight into the evolutionary history of an organization and can be a valuable tool for management when used to check if the organizations future plans are consistent with their understanding of the past. The use of cladistics allows for the measure of strategic excellence through the principle of parsimony. The process of conducting, documenting and co-ordinating comparative studies which are based on manufacturing organizations could be feasible if a cladistical classification of these systems were in place.. Cladograms could be used to represent the changing nature of manufacturing systems over time and as such they can provide valuable knowledge and insight into the changing characteristics which are exhibited by manufacturing systems throughout the course of their development.

By linking a classification to the process of change which occurs within the manufacturing industry, it can be hypothesised that distinct groups of manufacturing systems will emerge with their members possessing similar technological and behavioural attributes. As a result of this grouping there would now exist an "ideal model" or solution for the group. The "ideal model" developed for the group could be used as a means of developing solutions for individual companies within that group thereby reducing time and costs. Another valid reason for generating a manufacturing classification is based on its ability to facilitate predictions about systems behaviour. As the comparative study carried out enables the storage and retrieval of generalized information, this factor can help enhance investigators knowledge of the systems under study thereby allowing them to predict how these system will behave in the future. Product changes can and in most instances leads to a change in the way the manufacturing systems are designed or configured. It can also be envisioned that a newly installed manufacturing system or machines, would encourage product changes to utilize most of the extended system capabilities. Since "adding, removing, or changing manufacturing system’s modules changes its capabilities and functionality, the system would be capable of producing new product features that did not exist in the original products family" (Wiendahl et al 2007). Being able to manipulate the manufacturing systems capabilities and functionality allows the system to quickly respond to changes in its product variety as well as the increased demand for consumer customized products. The relationship which exists between products and the manufacturing systems that produce them provides the basis for studying the change mechanism(s) on both sides and investigating their boundaries, inputs and outputs.

A more recent example of the use of cladistics within the manufacturing environment was given by ElMaraghy et al (2008), where they utilised the techniques of cladistics when carrying out an analysis of an engine cylinder block manufacturer. They used this case study as an example to demonstrate the proposed cladistic analysis workings and merits. "The cylinder block variants belonged to automotive engines of different makes, material and types from Japan and North America, ranging in capacity from half a litre to six litres. The cylinder blocks are made of either aluminium or cast iron. They belong to either inline or V-type, high-deck or low-deck, front or rear wheel drive, overhead cam (OHC) or overhead valve (OHV) engines" (ElMaraghy et al 2008). The resulting cladogram was used to classify the evolutionary development of the engine cylinder blocks, as it embodied knowledge extracted from analysis to provide a valuable insight into both past and present manufacturing trends. Cladistics was also used to improve the current product variants families by determining the best family of products to which a new variant would best belong.

Building on their previous work carried out in 2008, AlGeddawy and ElMaraghy (2009) proposed an assembly systems layout design model for delayed product differentiation which was also based on cladistics. The main focus of their research was the design and synthesis of assembly systems layouts for implementing delayed products differentiation for a family of product variants. The case study carried out consisted of a family of five household products, with all members of the product family being heating appliances for water or food that share some common as well as distinctive features. Because of the similarities and differences these products were considered as candidates for being produced on a DPD assembly line. The information collected from the cladistical analysis facilitated the generation of the precedence charts of the family of the five products. "The precedence chart of a product is represented by a set of nodes and arrows, where each node consists of a component or a module that will be assembled to form that product, and arrows show the flow of the assembly steps, hence, each assembly precedence chart lays out the assembly map according to which the product components and modules are brought together, and its nodes and arcs represent the required assembly processes" (AlGeddawy and ElMaraghy 2009).

The evidence obtained from the literature review demonstrates the successful use of cladistics within the manufacturing environment as a decision making tool. The next section of this report will demonstrate the steps needed for constructing a cladogram of manufacturing system types

5.4 The Cladogram Building Process

The present manufacturing environment puts a tremendous amount of pressure on manufactures to offer a wider, more customized prodcut range to satisfy widening customer demands, whilst still maintaining a competitive pricing and logistical system. However in offering a widened product range manufacturers commit themselves to an expansion in the number of sub assembly processes as well as an increase in the level of raw materials which they need to stock in order to satisfy the increased product variation. Building on their work carried out in 2009 on delayed product differentiation, AlGedday and ElMaraghy employed the tools of cladistics in order to develop a model of a single assembly line which was applied to a group of automobile engine accessories which are normally assembled on different lines. Cladistics was used in planning the DPD assembly line configuration so as to incorporate the assembly precedence constraints, the required production rates of product variants and the existing production capacity of the work stations (AlGedday and ElMaraghy 2011). A group of five varying engine accessories were considered as part of the study with each normally produced using different assembly lines. Cladistics was used to determine the shortest possible evolutionary tree for the varying assembly lines based on a commonality analysis of components and assembly processes as well as to explore the possibility of unifying all the various assembly lines under a single assembly system. The end result of using cladistics to facilitate the design of this assembly system was an optimum balanced assembly line layout for the delayed product differentiation of automotive engine accessories.

The proposed framework for constructing a cladistic classification of manufacturing systems has been identified and adapted from classic biological approaches to cladism. The seven stages are listed below:

1) Select the manufacturing clade.

2) Determine the characters.

3) Code characters.

4) Establish character polarity.

5) Construct conceptual cladogram.

6) Construct factual cladogram.

7) Taxa nomenclature.

5.4.1 Selecting The Manufacturing Clade

The first step in generating the cladogram is determining the clade or variants which are to be studied. This initial step of determining which group of systems are to be included in the study can be considered as an informal form as classification. It was necessary to select a group of manufacturing systems which satisfy both the research objectives and interests. The selection of an industry which is well known and which has been widely studied brings with it certain advantages in terms of communicating, disseminating and validating the research carried out. The variants are usually taken from the proposed system which is being modelled and they represent the different types of similar or dissimilar elements which exist within the system. As the research focus thus far has been on identifying the different types of manufacturing layouts which exist, it is this collection of layouts which form the basis for our group of variants. The different types of layouts were identified after an extensive literature review was carried out in the field of manufacturing systems by the author, and they were found to be as follows; Fixed Position Layout, Job Shop, Cellular Manufacturing Systems, Flexible Manufacturing Systems, Reconfigurable Manufacturing Systems, Transfer Lines, Flexible Transfer Lines, Single Model Assembly Line, Batch Model Assembly Line, Mixed Model assembly Line and finally the Spine Layout.

One of the most important steps at this stage of the cladogram development process is the identification of the clade ancestor. This is usually done byconducting a process of historical investigation whereby data is gathered, reviewd and analysed to determine the origins of certain manufacturing types. The evidence collected to justify the clade ancestor was obtained from published materials, journal archives and books which all detail the manufacturing system along with a description of how that system operates and its defining characteristics. In the case of most manufacturing systems this would take the form of a craft system which evolves into an early factory system, eventually evolving to a mass producing system. For the purpose of this research the clade was defined as the Fixed Position Layout, with all the emergent systems being direct descendants of this manufacturing type.

5.4.2 Determining The Characters

Having determined the variants which are to be included in the study as well as the ancestor clade, the next step in the cladogram process is the determination of the characters for the study. When searching for characters that help distinguish the species phlogenetically it is helpful to know which characters to look for and which characters to avoid. "Whereas an attribute is a descriptive property or feature of a particular manufacturing system a taxonomic character has a distinctive feature which is used in the classification" (McCarthy et al 2000). One of the guidelines put forward by Sneath and Sokal (1973) highlights why certain types of characters should be excluded from taxonomic studies and why individuals should avoid searching for and selecting these characters which are totally inappropriate for this form of classification. These types of inappropriate or inadmissible characters can be either or all of the following;

Meaningless characters: The character chosen should be a true representation of the entity which is to be studied. An e.g. of a meaningless character would be the name of a manufacturing company included in the characteristics of a manufacturing system.

Logically correlated characters: Characters which have a logical consequence or dependence on one another should be avoided. For example a cellular based team requires a cellular layout in which to operate. This is a logical correlation between the two characters i.e. if one is present the other will also exist.

Partial logical correlation: Partial correlations amongst characters should be avoided. For e.g. the size of a workforce may be dependent on the number of machines used or it may be dependent on the level of technology or numerous other factors. These characters should be avoided.

Invariant characters: Characters which are normally variable, but which become invariable for the entities being studied should be avoided. An example of this is the absence or presence of manufacturing technology. When we consider the different manufacturing systems which exist this character will vary from one system to the other. This character would not change in a study of only manufacturing systems and should be avoided as these types of characters have no use in assessing similarities within the group.

One of the major advantages to the use of cladistics is in its ability to quickly eliminate characters which possess no evolutionary significance and to produce classifications objectively and efficiently. One of the key aspects to the generation of a reference list of characters is that it gives researchers a starting point from which they can generate a classification. Character selection within a study is ultimately governed by the existence of a synapomorphy which in turn results in a homology. Synapomorphic characters have a derived state and they are shared by two or more taxa's indicating the presence of a common ancestry for the group being studied.

These synapomorphic characters lead to a homology which indicates a "true similarity" between the entities of the group being studied. Following the guidelines mentioned above and after extensive research into the chosen manufacturing systems a total of 58 characters were identified. These characters are believed to account for the major differences between the various manufacturing systems layouts as they evolved.

5.4.3 Coding Characters

Having identified a set of characters which are to relevant to the variants being studied, the relationships between the characters and the variants are examined in order to facilitate construction of the cladogram. A cladistical character possesses three distinct properties they being direction, order and polarity and these allow construction of the cladogram from the character data collected. When referring to the characters direction one is actually referring to the characters transition between the various states. Once the direction of transformation has been established the character is said to be in a "polarised state". It should be noted that the coding of any character aids in the processing of the relevant character set. Figure 8 below depicts the character coding and polarization process.

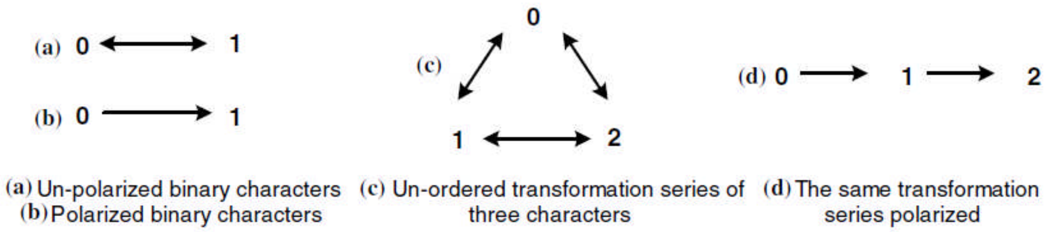


Figure 8: Character coding and polarity: Taken from McCarthy (2005)

5.4.4 <u>Establishing The Character Polarity</u>

In order to assess the polarity of any given character an outgroup comparison needs to be undertaken. The comparison is based on the premise that once the characteristics of the closest relative has been established, the information governing which character is identified as being primitive and which character is identified as being derived is revealed. Hence, "this comparison is based on the rule that for a given character with two or more states within a group, the state occurring in related groups is assumed to be primitive" (Watrous and Wheeler 1981). For any outgroup comparison two rules are used in order to satisfy the criteria of the comparison, they being the doublet rule and the alternating sister group rule respectively. The process of assigning a character's polarity needs to be conducted for each individual character within the study. This process plays a key role in identifying a characters polarity as well as aiding in the elimination of any conflicts which may exist within the cladogram.

From the information collected a total of 58 characters were identified from the literature review process and these charactersare believed to account for the major differences between the various manufacturing systems layouts as they evolved. Table 3 identifies these characters as well as their state variations and codes. For the different character states (0) means that the variant does not possess the character, is not used or in other words it is primitive, whilst (1) means that he variant possesses the character, is used and is therefore derived. In order to generate the data matrix the variants as well as the characters and their resulting character states are presented in table 5. At this stage it is worth noting that "the machine character is assumed to be in the primitive state as many of the different layouts identified tend to possess this character, which would eventually result in a more parsimonious cladogram, rather than assuming otherwise" (ElMaraghy et al 2008).

5.4.5 Constructing The Conceptual Cladogram

There are a number of tools that exist which allows users to generate cladograms which demonstrate the best estimate of the evolutionary relationships which are contained within the data matrix. There are two basic approaches to the design of a cladogram, they being;

1) Construction of the Cladogram from a given mathematical algorithm

2) Application of a specific criterion for selecting the most suitable cladogram from within the alternative cladograms generated.

Using a mathematical algorithm to generate the cladogram is the faster of the two options but this method fails to rank those trees which it regards as being sub-optimal. The application of a specific criterion generates a cladogram which has the rankings for all the trees generated. However it should be noted that this approach is only valid for those systems which have a maximum of 12 taxa. Beyond the 12 taxa mark the method is not able to generate accurate results due mainly to it suffering from computational difficulties. From the two methods discussed above the most popular method used in constructing a cladogram is the parsimony method. This is due to the fact that this method selects the shortest tree possible which in turn requires the least possible number of evolutionary character changes. Put simply the longer the cladogram tree length the worse the fit, whilst shorter the tree length, the more accurate the cladogram. The test of any given cladogram is in its ability to successfully explain the phylogeny of the selected clade. However along with this aim come two sets of conflicting problems. Firstly the proposed relationships generated by the cladogram may not be acceptable or historically correct and secondly there could be several conflicting cladograms of the same tree length.

The first step after the generation of the cladogram is to map the character state changes onto the tree diagram in order to obtain a wider view of the proposed phylogeny. In this way the cladogram can be shape tested by adding additional variants and characters. It is easier to add characters and species at this stage of the process as opposed to at the end of the clade building stage. On examination of the cladogram from the beginning, it is essential that the investigator establishes whether or not the addition of a character could result in the creation of a potential species and if enough historical data supporting the existence of this species exists, then the species should be added to the tree.

5.4.6 Constructing The Factual Cladogram

At this stage of the research the focus is on studying existing manufacturing organizations with the aim of observing the way these manufacturing systems actually operate. This task would usually be achieved through plant inspections / visits, through consultation with various employees and through an assessment of the company's records and procedure in relation to their planning and control. The main aim behind this task is the validation of the characters which have been identified during the cladogram development stage. This can be viewed to some extent as a validation exercise for the proposed cladogram as the factual data collected from the visit would be used to verify the conceptual data proposed. However, as no visits were undertaken to any manufacturing organizations the data used for the generation of the cladogram was purely conceptua. It was obtained from a review of the literature available on the various manufacturing system types that currently exist.

5.4.7 Taxa Nomenclature

The name assigned to any taxa or manufacturing organizations is more than a mere reference to the group. The name assigned must be unique and unambiguous and it should clearly display the taxa's position within the classification hierarchy.

The next section of this thesis provides some genral information on the cladistical package (MacClade) that was used to perform the cladistal analysis of the data collected. Some examples of MacClades use outside of the manufacturing environemnt are also described.

5.5 Information on MacClade

MacClade is used as a tool for phylogenetic analysis, but it is also used to portray a phylogenetic approach to studying diversity and evolution. Through observation it is relatively easy to see the diversity of living organisms, but depicting this diversity in regard to the organisms history has proved to be a very difficult task. MacClade has endeavoured to provide a means by which to present methods for analysing and exploring phylogenetic hypotheses, including hypotheses about the organism's character evolution. MacClade is one attempt to help us think about and see lineages and evolution.

To put it briefly, MacClade provides an interactive environment for exploring an organism's phylogeny. Through the use of MacClade's hypothesized phylogenetic trees or cladograms can be generated and manipulated and the organism's characteristics and character evolution can be made visible. In order to fully hypothesize the phylogenetic trees which are created a certain degree of tree manipulation is needed within the software parameters. Tools are provided to the end user to facilitate the movement of branches, the re-rooting of clades, to create polytomies and to search automatically for more parsimonious trees. Character evolution is reconstructed on the tree and indicated by "painting" the branches and alternative reconstructions of character evolution can be explored. A summary of all the character changes can be depicted on the tree and as trees are manipulated, MacClade updates statistics such as tree length with the results being depicted in graphics and charts.

The grand purpose behind the design of MacClade is "to help biologists explore the relationships between data and hypotheses in phylogenetic biology". The following are some examples of where MacClade has been used by biologists;

1. Knowles and Maddison (2002) in a paper titled Statistical phylogeography used MacClade to depict what would happen if the fields of parametric population estimation and geography were combined. They found that although methods for parameter estimation are now commonly used to make inferences about demographic past, these approaches are well developed statistically but pay little

attention to geographical history. In contrast, methods that seek to reconstruct phylogeographic history are able to consider many alternative geographical scenarios, but are primarily non statistical, making inferences about particular biological processes without explicit reference to stochastically derived expectations. They advocated the merging of these two traditions so that statistical phylogeographic methods can provide an accurate representation of the past, consider a diverse array of processes, and yet yield a statistical estimate of that history.

2. U'ren et al (2009) in a case study for analysing fungal environmental samples used MacClade to examine the diversity and evolutionary origins of fungi isolated from seeds of an important pioneer tree (Cecropia insignis, Cecropiaceae) following burial in soil for five months in a tropical moist forest in Panama. Fungi associated with seeds of tropical trees pervasively affect seed survival and germination, and thus are an important, but understudied, component of forest ecology. Their approach, which relied on molecular sequence data because most isolates did not sporulate in culture, provided an opportunity to evaluate several methods currently used to analyse environmental samples of fungi. Through the use of MacClade they found that common methods such as neighbour-joining and Bayesian inference differ in their sensitivity to alignment methods; analyses of particular fungal genera differ in their sensitivity to alignments; and numerous and sometimes intricate disparities exist between BLAST-based versus phylogeny-based identification methods. Their results illustrate the dynamic evolutionary relationships among endophytic fungi, pathogens, and seed-associated fungi, and the apparent evolutionary distinctiveness of saprotrophs.

For the purpose of this research the cladogram of manufacturing system types was constructed using the MacClade software package version 4.08 which was created by (Maddison and Maddison 2005). MacClade provides an interactive environment for exploring phylogeny and for also resolving character conflicts. The use of MacClade allows users to manipulate the final cladogram structure and character data and to visualise the proposed changes via the tree window. In order to manipulate the tree, tools are provided to move branches, re-root clades, and to facilitate the automatic search for the most parsimonious trees.

5.6 Generating the Cladogram

5.6.1 The Manufacturing System Type Characteristics

When identifying characters that help distinguish the species phlogenetically it is helpful to know which characters to look for and which characters to avoid. One of the guidelines put forward by Sneath and Sokal (1973) highlights why certain types of characters should be excluded from taxonomic studies and why individuals should avoid searching for and selecting these characters which are totally inappropriate for this form of classification. Bearing this in mind, the characteristics used in constructing the system layout type cladogram were compiled after an extensive review of the literature available on the manufacturing system types that exist. Upon collection of the information, the list of characters compiled from the data search had to be firstly reviewed then edited so as to omit any duplicate records which may have appeared. The characters were then checked to ascertain their relevance to the variants chosen for this study and then added to the finalized character list.

The characteristics compiled in table 5 belonged to one of three distinctive groupings which were a representation of the volume of production undertaken. These groupings were, low volume production, medium volume production and high volume production respectively. The charactestics assigned to these groupings were derived from the papers collected and reviewed in the literature review process.The characteristics also addressed the level of flexibility present in the manufacturing environment as well as the level of system reconfigurablity. It should be noted that the 58 characteristics identified do not appear in total in any of the given variants. The characteristics act as a great differentiator in distinguishing the various manufacturing system types. However, it should be noted that one of the key aspects to the generation of a reference list of characters is that it gives researchers a starting point from which they can generate a classification.

Table 5: The manufacturing system type characteristics

No.	Characteristic	State	Description
1	Part Flow	0 1	No Yes
2	Low Volume of production	0 1	No Yes
3	Highly Skilled Labour	0 1	No Yes
4	Wide Product Range	0 1	No Yes
5	Grouping of Resources	0 1	No Yes
6	General Purpose Equipment	0 1	No Yes
7	High Operational flexibility	0 1	No Yes
8	Production Based on Processing Needs	0 1	No Yes
9	No Fixed Part Route	0 1	No Yes
10	Medium Volume Production	0 1	No Yes
11	Is Based on Grouped Technology	0 1	No Yes
12	Has Production Centred Around Part Families	0 1	No Yes
13	Has Low to Medium Batch Processing	0 1	No Yes
14	Has Machine Flexibility	0 1	No Yes
15	Has Routing Flexibility	0 1	No Yes
16	Has Production Flexibility	0 1	No Yes
17	Each Part Has a dedicated Production Cell	0 1	No Yes
18	Mix Between Process & product Based Systems	0 1	No Yes
19	Long Setup Time	0 1	No Yes
20	Computer Controlled System	0 1	No Yes
21	Integrates the Use of Programmable Technologies	0 1	No Yes
22	Has an Automated Material Handling System	0 1	No Yes

23	Automated Machine Loading	0 1	No Yes
24	Made up of CNC Workstations	0 1	No Yes
25	Has Process Flexibility	0 1	No Yes
26	Has Product Flexibility	0 1	No Yes
27	Has Expansion Flexibility	0 1	No Yes
28	Has Modularity	0 1	No Yes
29	Has Intergrability	0 1	No Yes
30	Has Customization	0 1	No Yes
31	Has Convertibility	0 1	No Yes
32	Has Scalability	0 1	No Yes
33	Has Diagnosability	0 1	No Yes
34	Is a Flowline System	0 1	No Yes
35	Large Volume Production	0 1	No Yes
36	Has Standardisation of Parts	0 1	No Yes
37	Has Automated Transport System	0 1	No Yes
38	Has Dedicated Automation	0 1	No Yes
39	Has Workstations Arranged Along a Fixed Path	0 1	No Yes
40	Sequential Movement of Work Along the Line	0 1	No Yes
41	Is Highly Flexible	0 1	No Yes
42	No Product Variation	0 1	No Yes
43	Production Done in Batches	0 1	No Yes
44	Automatic Machine Changeover	0 1	No Yes
45	No Machine Changeover Needed	0 1	No Yes
46	Has Standardised Assembly Times	0 1	No Yes

47	Has line Balancing	0 1	No Yes
48	Has excess Capacity	0 1	No Yes
49	Sequential Dependence on Workers	0 1	No Yes
50	Two or More Models Produced	0 1	No Yes
51	Workstations Can Be Reconfigured	0 1	No Yes
52	Workstation Setup Needed Before Product Changeover	0 1	No Yes
53	Changeover Needed	0 1	No Yes
54	Has Multifunctional Workstations	0 1	No Yes
55	Different Models Made Simultaneously on the Same Line	0 1	No Yes
56	Has Main & Mini Assembly Lines	0 1	No Yes
57	Suppliers Can Be Located on Site	0 1	No Yes
58	Has a Shared Material Handling System	0 1	No Yes

5.6.2 The Combined Component Characteristics

The data collected on the various manufacturing system types that exist was useful in identifying the evolutionary pattern of manufacturing systems thus far, but this alone was not sufficient to develop a simulation based template modelling library. As the characteristics identified looked at the various similarities and difference which these systems possess, a more in depth review of the data was needed in order to identify the actual physical configurations of these systems. Information on the mix of automation, manpower and machinery as well as information on the various transport systems used was also needed. From the data collection process the evidence collected pointed to numerous configurations of system components, however this data was only made useful after cladistics was used to classify the information collected. However, it should be noted that as the models generated were built using the Witnss simulation software some of the characteristics obtained were relevant to that particular modelling system.

Table 6: The combined component characteristics

No.	Characteristic	State	Description
1	Existence of a Constraint	0 1	No Yes
2	Resource Required for Operation	0 1	No Yes
3	Part Queue	0 1	No Yes
4	Used for Storage	0 1	No Yes
5	Quantity	0 1	No Yes
6	Input Rules	0 1	No Yes
7	Output Rules	0 1	No Yes
8	Has Cycle Times	0 1	No Yes
9	Processing Parts	0 1	No Yes
10	One Part in	0 1	No Yes
11	One Part Out	0 1	No Yes
12	Many Parts In	0 1	No Yes
13	One Part Out	0 1	No Yes
14	Follows First In First Out Rule	0 1	No Yes
15	Two Parts Out	0 1	No Yes
16	Needs a Batch Minimum	0 1	No Yes
17	Needs a Batch Maximum	0 1	No Yes
18	Can Run Multiple Cycle Times	0 1	No Yes
19	Produces a Finish Quantity	0 1	No Yes
20	Produces a Output Quantity	0 1	No Yes
21	Material Handling	0 1	No Yes
22	Capacity	0 1	No Yes

23	Has an Index Time	0 1	No Yes
24	Has a Maximum Length	0 1	No Yes
25	Length of Track	0 1	No Yes
26	Maximum Speed	0 1	No Yes
27	Start Time	0 1	No Yes
28	Stop Time	0 1	No Yes
29	Loading Speed	0 1	No Yes
30	Unloading Speed	0 1	No Yes
31	Has Repeatable Components	0 1	No Yes
32	Uses Machines	0 1	No Yes
33	Has Input Elements	0 1	No Yes
34	Has Output Elements	0 1	No Yes
35	Has Push Rules	0 1	No Yes
36	Has Pull rules	0 1	No Yes
37	Has Interconnectivity	0 1	No Yes
38	Has Pre Determined Logic	0 1	No Yes
39	Uses Tracks	0 1	No Yes
40	Made Simultaneous Models On The Same line	0 1	No Yes
41	Uses Reconfigurable workstations	0 1	No Yes
42	Machine Changeover Time Required	0 1	No Yes
43	Presence of a Multifunctional Workstations	0 1	No Yes
44	Uses Input and Output Buffers	0 1	No Yes
45	Sequences to Two or More Components	0 1	No Yes
46	Uses Percentage Rule	0 1	No Yes

47	Uses Sequence Next/ Wait Rule.	0 1	No Yes

5.6.3 The Data Matrices

The process of phylogenetic analysis mainly consists of two phases. Firstly a data matrix is assembled, and then a phylogenetic tree is inferred from that matrix. There is obviously some feedback between these two phases, yet they remain logically distinct parts of the overall process. One could easily argue that the first phase of phylogenetic analysis is the most important: the tree is basically just a re-representation of the data matrix with no value added. This is especially true from a parsimony viewpoint, the point of which is to maintain an isomorphism between a data matrix and a cladogram. Despite the logical pre-eminence of data matrix construction in phylogenetic analysis, the greatest effort thus far in phylogenetic theory has been directed at the second phase of analysis, the question of how to turn a data matrix into a tree. It is argued that if care is taken to construct an appropriate data matrix to address a particular question of relationships at a given level, then simple parsimony analysis is all that is needed to transform that matrix into a tree.

The character matrix shows that each taxon has a different combination of features, or traits. Not all morphological traits provide useful phylogenetic information and until the matrix has been constructed it may not be obvious which characters are informative and which are not. The characters used to construct the cladogram must be carefully chosen and they need to be consistent in all the members of that type of organism. In selecting the suite of characters to be compared, each organism must have at least one character different from the other organisms. A plesiomorphy is an "ancestral", "less specialized", or "primitive" character, while an apomorphy is a "derived", "specialized", or "advanced" character. Every taxon possesses a mixture of plesiomorphies and apomorphies characters. However, researchers can define character states as they choose by examining the taxa and scoring the matrix based upon their observations. From this they can construct the cladogram by working their way up the tree by building parsimonious relationships of the taxa’s.

From the data collected a total of 58 characters were identified which are believed to account for the major differences between the various manufacturing systems layouts as they evolved. Table 5 identifies these characters as well as their state variations and codes. For the different character states (0) means that the variant does not possess the character, is not used or in other words it is primitive, whilst (1) means that he variant possesses the character, is used and is therefore derived with respect to the presence or abssence of the character in the outgroup. In order to generate the data matrix the variants as well as the characters and their resulting character states are presented in table 7. The data matrix is constructed by constructing a table of the variants which make up the clade verses the characters identified from the study. The corresponding (0) and (1) values are inputted into the matrix with the corresponding value denoting the presence or absence of a respective characteristic.

The data collected from the literature review exercise also identified a total of 19 separate variants, all of whom to some degree or another influence the component choice within a simulation based environment. Variants started out as simple single elements and became more and more complicated as they evolved, eventually evolving into sets of varying combined components. The same principles were applied to develop the list of combined component characteristics for the study. The end result of this exercise was the identification of 47 characters which facilitated the combination of simulation based components. The characters and variants were tabulated in order to create the data matrix for the combined component cladogram as shown in table 8 below.

Table 7: The Layout Type Data Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
Fixed Position	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Job Shop	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cellular	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flexible Manufacturing System	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reconfigurable Manufacturing System	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transfer Line	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flexible Transfer Line	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Model Assembly Line	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
Batch Model Assembly Line	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0
Mixed Model Assembly Line	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	1	1	0	0	0	0	1	0	1	1	1	0	1	0	0	0	1	1	0	0	0
Spine	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	0	1	1	1	0	1	0	0	0	1	0	1	1	1

Table 8: The Combined Component Type Data Matrix

Variants / Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Resource	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buffer	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Machine	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assembly Machine	0	0	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Production Machine	0	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Batch Machine	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MultiCycle Machine / Palletizer	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conveyor	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Track	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AGV's / Cranes	0	0	1	1	1	1	1	0	0	0	0	0	0		0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Machine + Buffer	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Machine + Buffer + Labour	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Machine + Conveyor	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Machine + Buffer + Conveyor	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Machine + Conveyor + Labour	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Machine + Buffer + Conveyor + Labour	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Machine + Buffer + Conveyor + Labour + AGV's / Cranes	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Machine + Buffer + Conveyor + Labour + Robot / Palletizer	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0
Sequence Machine	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1

5.6.4 Calculating the Tree Position

Phylogenetic trees or evolutionary trees are binary trees that describe the “relations” between species. Trees consist of nodes or vertices and taxes or leaves. To understand the data contained in these trees, one must understand some of the methods behind phylogenetic trees or evolutionary trees. Some of these methods are depicted in figure 9 below.

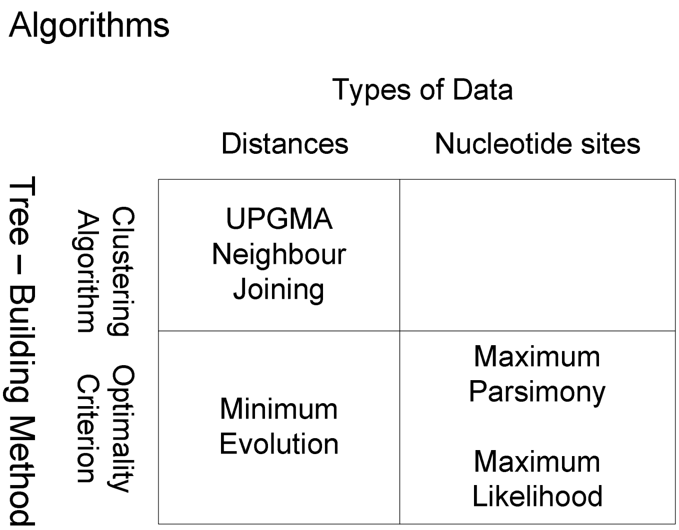


Figure 9: The data algorithms*: Taken From Page and Holmes: Molecular Evolution: A Phylogenetic Approach Pg 178*

There are two basic methods for constructing trees they being;

Cluster methods: This method uses an algorithm (set of steps) to generate a tree. These methods are very easy to implement and hence can be computationally efficient.

***Search methods*:** These methods use some sort of optimality criteria to choose among the set of all possible trees.

As MacClade uses a combination of the above mentioned algorithms to generate potential trees from the data matrix, the computational power of the software would not be discussed in any great detail. However the UPGMA method would be used to demonstrate how potential trees can be calculated. The unweighted paired group method with arithmetic mean (UPGMA) is typically used to cluster molecular data where the sequence alignment distance, between sequences has been determined in a distance matrix. In order to demonstrate how this method is used to calculate the position of taxa's on relevant trees let's look at the following example shown in table 9 is used to calculate the position of the taxa "Bear" in the cladogram using the UGPMA method mentioned above.

At each stage of the method the smallest entry is located and the entries intersecting at that cell are "joined". The height of the branch for this junction is one-half the value of the smallest entry. Thus since the smallest entry at the beginning is 1, the branch height = 1.0 /dmin = 1 / 2 = 0.5. The comparison matrix is reduced by combining cells.

Table 9: The UGPMA data sample

Characters		Backbone	Jaws	4 Limbs	Amniotic Egg	Mammary Glands	Opposable Thumbs	Upright Posture
Taxa		A	B	C	D	E	F	G
Lizard	A	0	0	0	0	0	0	0
Human	B	20	0	0	0	0	0	0
Sunfish	C	27	32	0	0	0	0	0
Newt	D	9	19	27	0	0	0	0
Lamprey	E	34	36	42	32	0	0	0
Chimpanzee	F	19	1	33	18	35	0	0
Bear	G	14	15	28	13	27	14	0

The UPGMA method shown in figure 9 is applied to the table 9 data sample. At each cycle of the method, the smallest entry is located, and the entries intersecting at that cell are "joined." The height of the branch for this junction is one-half the value of the smallest entry. Thus, since the smallest entry at the beginning is 1 (between B=man and F=monkey), B and F are joined with branch heights of 0.5 (=1.0/2). Then, the comparison matrix is reduced by combining cells. These combinations are indicated with colours in figure 10 below. For example, the comparisons of A to B (20.0) and A to F (19.0) are consolidated as 19.5 = (20.0+19.0)/2 (**red cells**), while the comparisons of E to B (36.0) and E to F (35.0.) are consolidated as 35.5 = (36.0+35.0)/2 (**blue cells**).

The process is repeated on the reduced comparison matrix, resulting in a smaller matrix with each cycle. When the matrix is completely reduced, the calculation is finished.

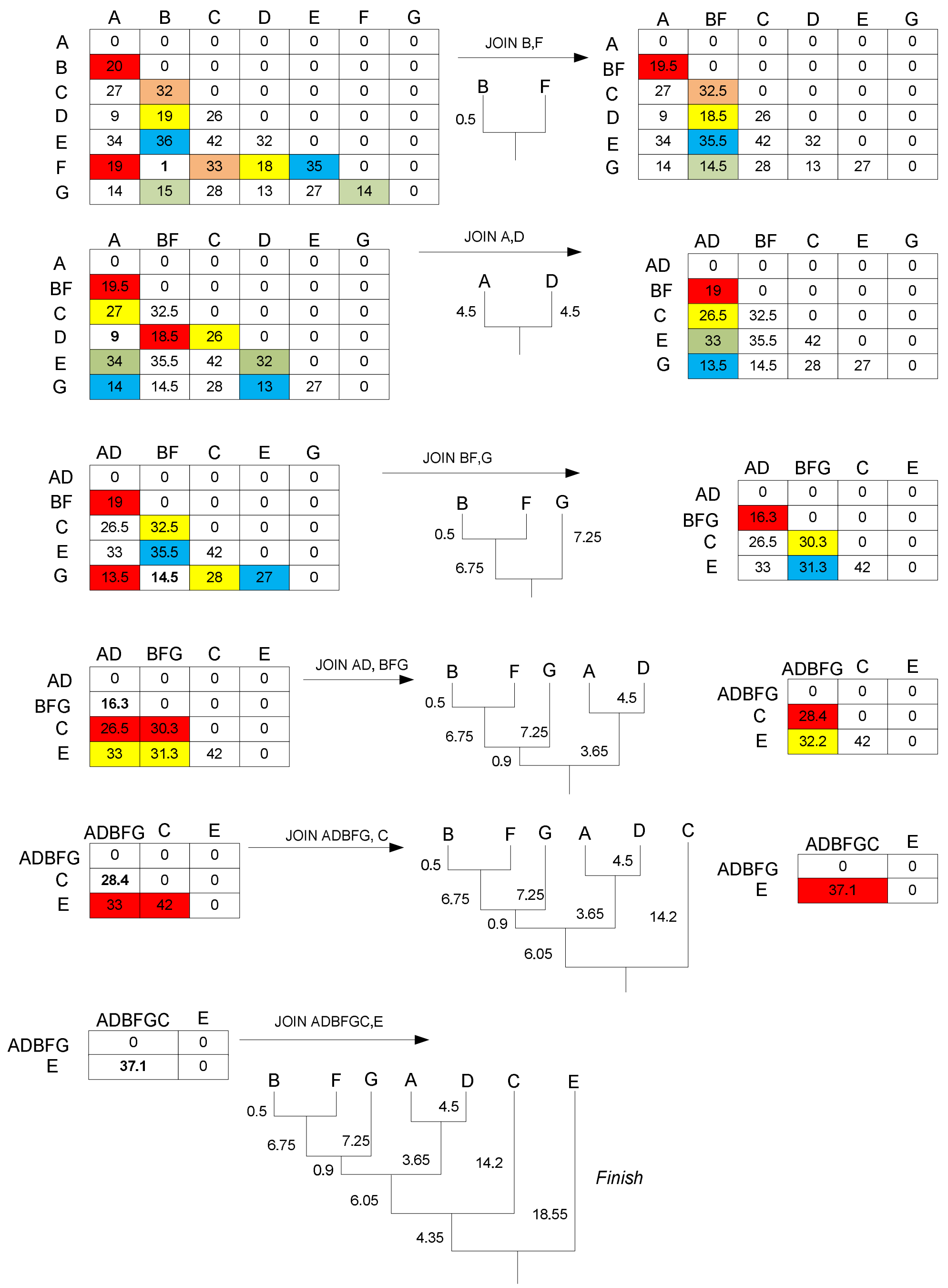


Figure 10: The UGPMA example

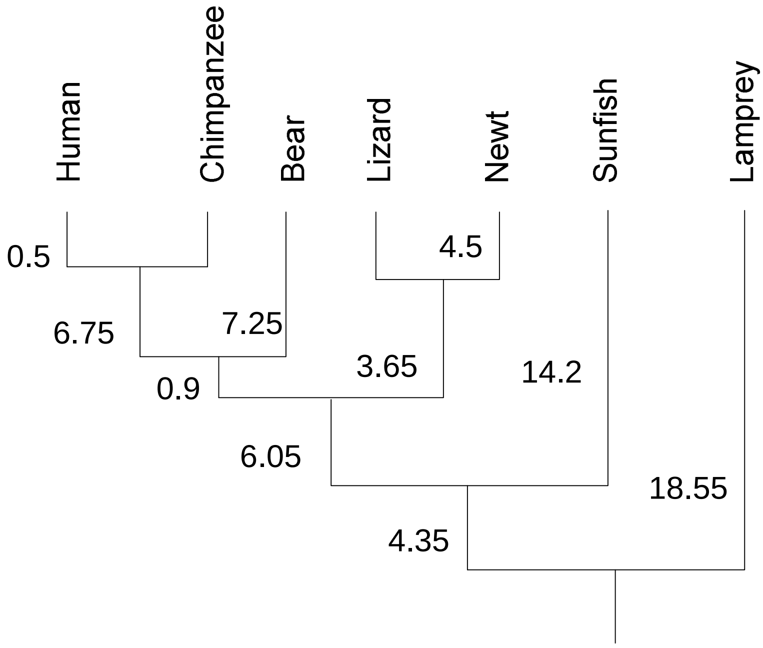


Figure 11: The completed cladogram showing the position of "bear" in the taxa

5.6.5 The Cladogram of Manufacturing System Types

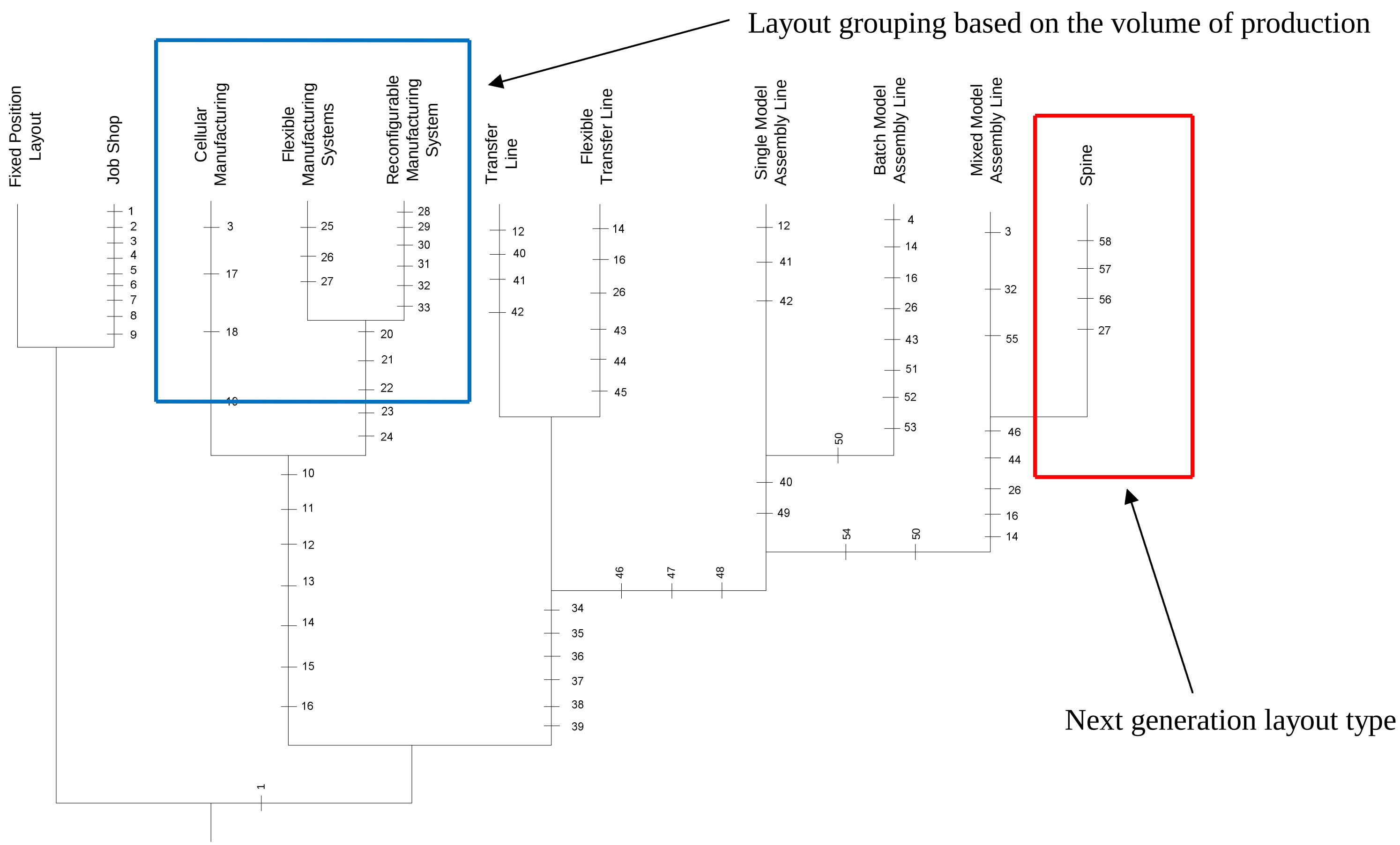


Figure 12: The Layout Type Cladogram of Manufacturing System

5.6.6 *The Cladogram of Combined Component Types*

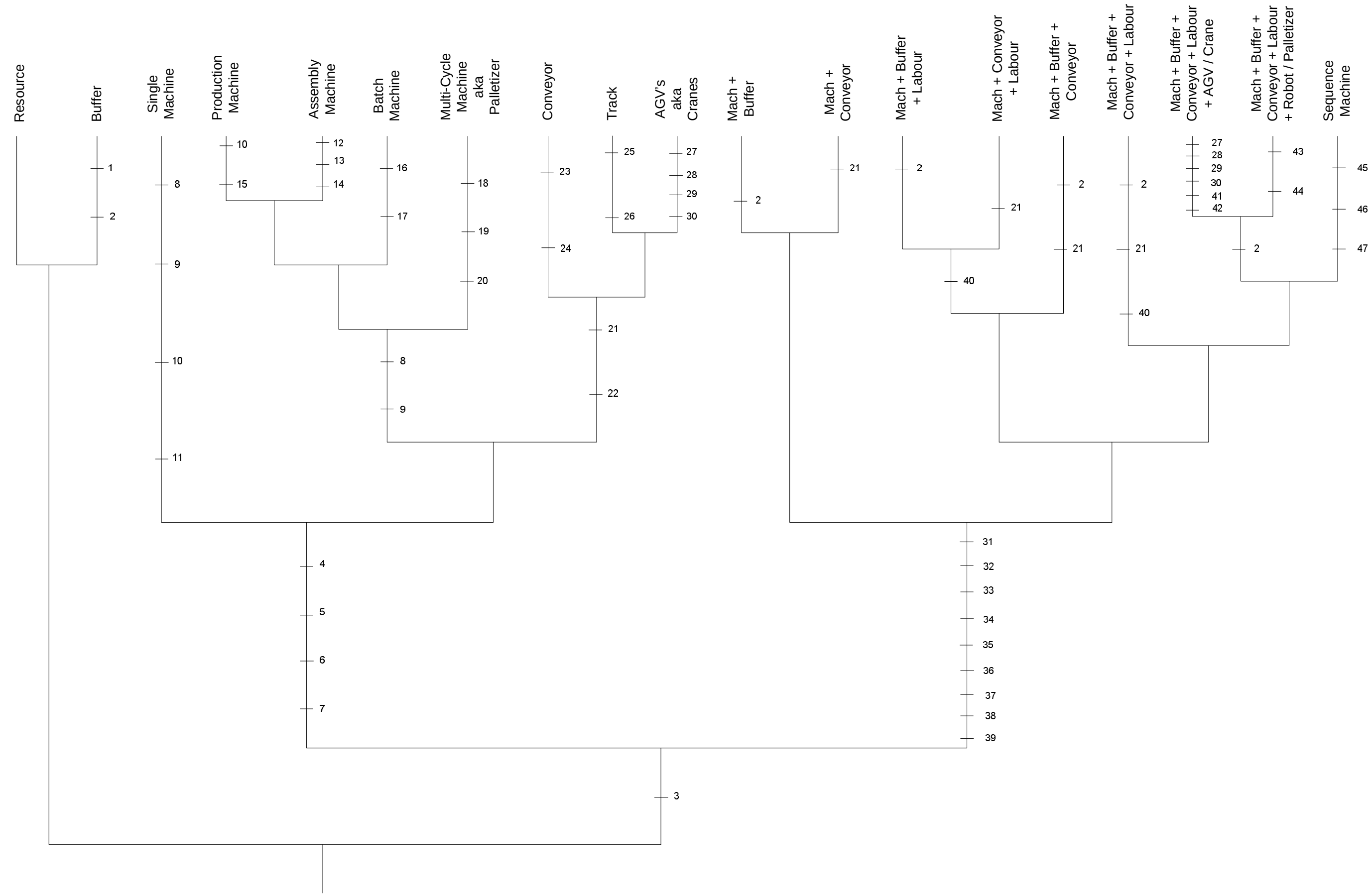


Figure 13: The Combined Component Type Cladogram

5.6 Analysis of the Cladogram

Cladistics analysis relies on the similarity of characters, regardless of chronological events or time scale, to provide an evolutionary hypothesis. This fact is useful within the context of the manufacturing environment, as innovations tend to appear as irregularities in the evolution path when taken in their chronological order (ElMaraghy et al 2008). By applying the process of cladistical analysis to the data collected the information is rearranged, and then re-inserted into the evolution path, thereby forming a regular pattern. Use of a cladogram can help in establishing the overall evolutionary picture, as layout variations that occur via multidirectional evolutionary branches can be streamlined to show how innovation and improvements affect the evolutionary path.

Part of the cladogram building process relied on the manual development of the cladogram based on the data collected and analysed from the literature review. This process enabled the authour to manually construct the trees and branches for both cladograms based on the data contained in the data matrix. This manual cladogram was vital to the cladogram building process as it was used as a means of verifying the claodgrams generated via the MacClade software package.The information collected and analysed on the various manufacturing types that exist produced a cladogram with 3 distinct groupings (figure 12) based on the manufacturer’s volume of production. Manufacturing system types belonged to a low volume, a medium volume or a high volume production system.

Analysis of the cladogram showed that at each level the variants can be grouped into sets which support the theory of evolving manufacturing layouts, while still retaining some similarities amongst the variants. From the cladogram it can be seen that all production systems to date emerged or evolved from a fixed position layout and as resources increased, progressed to a traditional job shop production system which had general purpose equipment, skilled labour and operational flexibility. Production in the job shop environment was entirely based on the manufacturers processing needs. As technology and the use of computational resources increased along with consumer demand, the layouts used in the manufacturing processes also evolved.

There was now a move from the low volume manufacturing system to that of a medium volume system that incorporated grouped technology as the base for its evolution. Production was now concentrated around part families with products being produced by low to medium volume batch processing systems. These systems now possessed greater machine flexibility, routing flexibility and production flexibility as opposed to the previous low volume production systems. They have also become fully computer controlled and integrated the use of programmable technologies into their manufacturing operations. One of these systems, the flexible manufacturing system now possessed greater expansion flexibility allowing it to adapt to changes in consumer demand and technology.

High volume production systems make up the basis for our final group of production systems in the generated cladogram. These systems have been around for a long time and analysis of the literature has shown that these that tey are considered to be more evolved than medium volume systems as they incorporate a greater standardisation of parts, standardised assembly times, dedicated automation and automated transport systems. Mass producing systems also employ the concepts of line balancing and excess capacity. Some mass producing systems for e.g. the batch model assembly line take the concept of flexibility and reconfigurability which was derived in the medium volume production systems and apply it to a high volume production system. Some mass producing systems such as the mixed model assembly line allow for different models to be made simultaneously on the same line whilst allowing the system to have a greater degree of scalability. What the cladogram also depicts is the emergence of next generation type layouts such as the spine layout. These systems possess greater expansion flexibility than previous mass producing systems and they allow for main and mini assembly lines as well as for suppliers to be located directly on site. As a result of these factors these systems are emerging as the next logical step in the evolution of manufacturing system layout types.

The information presented in the cladogram of combined component types (figure 13) was collected after an extensive review of data on real world manufacturing systems. Real world systems in the context of this research refers to manufacturing systems which have been detailed and documneted and are not theoretical but exist in various manufacturing environments.The various configurations of these systems were analysed and the results depicted in the final cladogram. Analysis of this cladogram showed that components used in the manufacturing environment started out as single elements but with time they evolved into various combined component types. Elements or (Variants) were all considered to be active and to be derived from a resource. The logic rules which were used for modelling single elements also evolved as the component type evolved with the rules becoming more complex as the complexity and functionality of the combined components increased. From the data analysed it was found that certain repetitive patterns were becoming more frequent and in use throughout a number of different manufacturing systems. For example. the use of a machine combined with a buffer (manual or automatic) or the use of a machine combined with a conveyor was found to exist in a number of the real world systems identified in the system type cladogram.

Since cladistics can be used to identify the current layout variants / families and groups, it can also provide guidance for deciding upon the relevance of a new layout within an existing group / family of variants. The author hopes that by having this classification scheme in place the simulation process can be expedited, as templates within the modelling library can be built with a specific group of layouts in mind.

5.7 Summary

After reviewing the current literature on the use of cladistics it was found that not only has the use of cladistics become more widespread in the field of classification but its use is also becoming more widely adopted in the manufacturing sector. The Construction of a classification using evolutionary relationships was considered to be beneficial, as the classification would be unique and unambiguous thereby showing only the true relationships which exist between the various layout and component types. With this in mind two distinctive cladograms were developed depicting the evolutionary path or the various manufacturing system types identified as well as the evolutionary path of their system components. The scope of the work carried out in this chapter will form the basis of the next chapter as the information presented here will be used to construct the template based modules and the modelling library.

Chapter 6

Development of a Rapid Model Generator Prototype

6 DEVELOPMENT OF A RAPID MODEL GENERATOR PROTOTYPE

6.1 Introduction

Model building can be viewed as one of the key steps in any simulation study that requires simulation modellers to fully understand the problems and to envisage and construct the model elements and relationships which logically link them together (Guru & Savory, 2004). McLean and Leong, (2001) and Onggo et al (2006) who suggests that "introducing the concept of modularity into the simulation process can be one way to simplify the model generation process as well as the construction of reusable simulation data and codes" (McLean and Leong, 2001).The need of manufacturers to adhere to widening consumer choice means that "there is now a call for greater flexibility and efficiency in the sector to respond ably and in time to the changing production quality as well as process requirements" (Heilala et al., 2007). When the complex process of simulating production facilities is combined with the time consuming process of model building, more innovative and faster techniques of using simulation have to be adopted. It is with the specific purpose of increasing the speed of building simulation models in industry that the use of generic simulation modules has been adopted.

A simulation model can be quickly created if it can be assembled by adding the building blocks (modules) in a model template. A template, in the context of simulation and modelling, is referred to as a collection of user-defined, ready-to-use and re-usable building blocks that are created by programming their functionality, interface and performance indicators in an appropriate simulation environment. In order to develop a module that has the ability to be reused in different models under different conditions, the module must contain all if not most of the details and entities needed by the model. The collection and integration of the attributes, variables and entities in a logical way represents the method to create a generic simulation module. A completed module contains all the necessary modelling components (machines, buffers, conveyors etc.), routing logic and interconnectivity which are all pre-loaded on the module template and allows the module to function as a single element or be combined with other elements in order to form a simulation model. A completed module also enables the modeller to use it in the model with little or no modifications. The concept of 'model reuse' has gained momentum in the simulation modelling community.

The concept of modellers being able to use and reuse models and modelling components developed by themselves, as well as others, thus saving time, money and effort was found to have certain merits and technological advances and have made it more viable. In order to create a simulation model the modules are combined based on the requirements of the end user and the system to be modelled. In the conceptual simulation model, model generation takes place when modules and data from an interface are added and assembled on the model template. For automatic generation of simulation model and making the simulation tool user-friendly, the functionalities within the simulation software is used and a secondary user interface built using Microsoft Excel is used for transferring data into the simulation software. The use of a secondary user interface helps the modeller transfer the data required for model detailing, thus avoiding the time consuming process of creating and detailing all the entities. As this chapter progresses the work carried out will detail the module and model building process as well the RapidSim approach to model generation.

6.2 Module Creation and Use in Industry

The development of simulation models can be a sometimes length and very cumbersome process which can be made easier and over the years a number of potential solutions to this problem have been suggested by various people researching into this field. Willemain in his study conducted in 1995 found that during the model building process almost 60% of the time was spent on understanding and developing the structure of the model. Model building can be viewed as one of the key steps in any simulation study that requires simulation modellers to fully understand the problems and to envisage and construct the model elements and relationships which logically link them together (Guru & Savory, 2004). Solutions to this problem were put forward by McLean and Leong, (2001) and Onggo et al (2006) who suggests that "introducing the concept of modularity into the simulation process can be one way to simplify the model generation process as well as the construction of reusable simulation data and codes"

(McLean and Leong, 2001). Pidd (2004) suggested that the modular approach to any type of simulation modelling would be a beneficial tool to modellers as this approach would be able to deal with the increasing size and complexity of simulation models. Kilgore et al (1998) also postulated that developing and using modules as standardized and repeatable simulation components in the simulation modelling process can help in reducing the level of difficulty associated with the task of designing and building a simulation model.

In a study conducted by Tjahjono and Baines (2004) where simulation was found to be widely adopted in industry, they noted that over the years there has been an increase in the use of simulation by personnel such as manufacturing engineers, production planners etc., who are not experts in the field of simulation or simulation modelling. Knowing this has enabled simulation modellers to take steps aimed at simplifying or making simulation tools easier to use, and this in turn helps in speeding up the entire model building process. Some of the steps which have been taken thus far to aid in this process include the use of component modelling (Pidd et al, 1999) model building using a predefined template (McLean and Leong, 2001) creation of a secondary user interface for data input/output (McKenna and Little, 2000; Ladbrook and Januszczak, 2001), and rationalisation of data format (Robertson and Perera, 2002).

6.3 Generic Module Creation

Today’s market pressures from low-cost economies translate into ever increasing demands for wider product variety, faster delivery times, improved quality and reduced cost, which puts pressure on system designers for more innovative and adaptive manufacturing systems. As a result of the increase in global productivity and demand, production systems are being designed and redesigned at an increased rate and they are becoming more innovative as they progress with time. The use of simulation technologies enables manufacturers to carry out “what-if” scenarios that are useful in gaining a deeper understanding of how a new or alternative manufacturing system will perform before any investments or modifications are made. Evidence in support of the use of simulation technology was found by Heilala et al., (2007), who stated that “In this field where the demands of the customer have to be met at the minimum cost and effort as well as within the stipulated time period, there is an urgent call for speed as well as flexibility Systems, processes and data are constantly growing and thus become more intricate".

Over time there has been an increase in demand from consumers for products which need to be customised to suite their specific need and requirements. This change in the pattern of consumer demand has been fuelling the radical changes which are now taking place within the manufacturing sector. An e.g. of this pattern of change is in the manufacturer of a motor vehicle. Consumers are now given a wide range of additional choices such as the choice of colour, the choice of interior finishing's or the choice of wheel sizes etc. This need to adhere to the consumers every need means that "there is now a call for greater flexibility and efficiency in the sector to respond ably and in time to the changing production quality as well as process requirements" (Heilala et al., 2007). Within a production facility the manufacturing, production and service decisions need to be made in conjunction with considerations of multiple interdependent factors and variables. One of the ways in which the decision making process and manufactures response to customer needs can be speeded up is through the use of template based modelling. Generic moduls which can be quickly assembled on a model template can help facilittae faster simulation modelling and improve the decision making process.

The simulation process is often complex and "are probably too many for the human mind to deal with at one time" (Heilala et al, 2007). When the complex process of simulating the real world production facilities is combined with the time consuming process of model building, more innovative and faster techniques of using simulation have to be adopted. It is with the specific purpose of increasing the speed and uptake of simulation models in industry that the use of generic simulation modules has been adopted. A simulation module can be quickly created if it can be assembled by adding the building blocks (modules) in a model template. In order to develop a module that has the ability to be reused in different models under different conditions, the module must contain all if not most of the details and entities needed by the model. For e.g. the module must be able to store data such as routing commands, input and output rules and it must also be able to foster interconnectivity and complexity when used on its own or in combination with other similar or dissimilar modules in order to create a completed model. The modules ability to store data can be seen as the most important aspect of its creation as this data will facilitate in the overall model building process.

The actual facility representation within the module can be achieved by indicating the behaviour provided by the entity in terms of the attributes and variables. When a module is created as a representation of a generic modelling scenario the level of complexity involved in creating the module increases exponentially as the variables needed for module creation increase proportionately. When the entities, variables and attributes needed by the module are collected and integrated into the module in a logical way only then can the creation of a generic simulation module take place. A completed module would in all aspects allow simulation users to use in within a simulation model with some degree of modification as the module already has all the necessary logic commands, routing information and interconnectivity built into it. The process shown in figure 14 below depicts the creation of a simple easy to use module which is made up of the four basic components of a simulation model; a machine, a buffer, a conveyor and a labour. However it should be noted that although only 4 components are depicted in the diagram as examples, the component mix could be made up of any number of varying components depending on the requirements of the end user.

The elements which are needed to construct the module are made up of input and output rules which are used to control the flow and direction of parts in and out of the system. The interconnectivity between the elements used is maintained through the use of instructions which are defined within the elements operational parameters and which can be used to control the movement of parts between the elements. In Witness selecting the elements that are to make up the module and then using the "create module button" on the element toolbar, creates a simulation module. At this time the attributes and variables which are required for detailing parameters of these elements can also be added into the module and they become part of the module’s logic structure. Within the module the way each element works needs to be specified in regard to the input and output logic needed for the module to operate and to communicate with other modules or elements. After detailing and defining the entities of the elements of the module, these are externally stored as an '*.mdl' (where * represents a valid simulation filename) file. The modules act as discrete independent self-containing elements that can be used on their own or which can be combined with other modules or elements to create more complex modules for use in different simulation models.

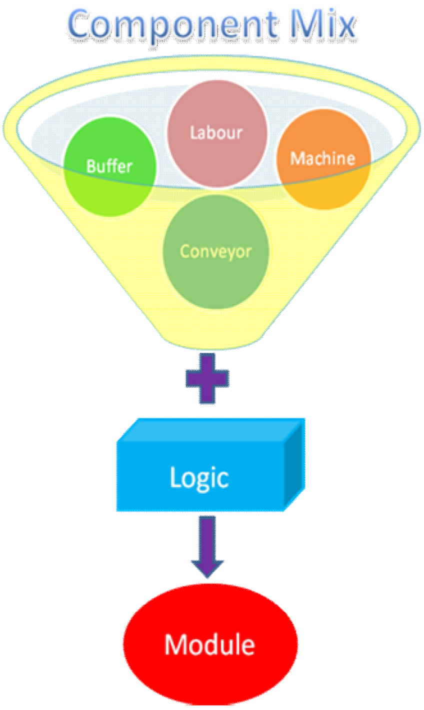


Figure 14: Creation of a generic simulation module

The approach mentioned above can be seen as the typical method of designing a simulation module. The modules created for this part of the study needed to be a true representation of the components or the combination of components which are in use within the manufacturing system layouts identified in chapter four. To aid in creating the necessary modules a study was undertaken to identify the component or group of components which were found to repeat themselves in the layouts identified. An excerpt of the findings for this exercise can be found in table 10 below, while the complete list of components and their configurations can be found in Appendix 2 at the end of this report.

However, this method of module creation needed expansion in the case of the RapidSim model as the modules developed for this research will be based on the cladistical analysis carried out in chapter 5. The findings presented in table 10 will be used in conjunction with the information presented in the cladogram to develop the generic simulation modules for this research. Figure 15 below illustrates the concept of creating a module library based on layout and component type information obtained from the cladogram.

The main objective of building of a library is to store the created modules, template and interface and making them easily retrievable for generating the simulation model. The library contains data storage entities that represent each of the identified manufacturing systems and it houses the Witness file that represents the template for the model, module file that represents the building blocks for the model and user interface file for data input. These files are stored in *.mod, *.mdl and *.xls file formats

This library offers the modeller with a set of pre-developed templates, modules and interface file of different layouts that could be used to assemble a model quickly. However, it must be noted that the assembled model may require some modifications to suit the requirements of the user. Even though a modeller can easily retrieve the modules from the library, user should possess some basic of the simulation software in order to use them. Easy availability and the retrieval of modules for the quick generation of simulation models is the basic requirement behind the whole process.

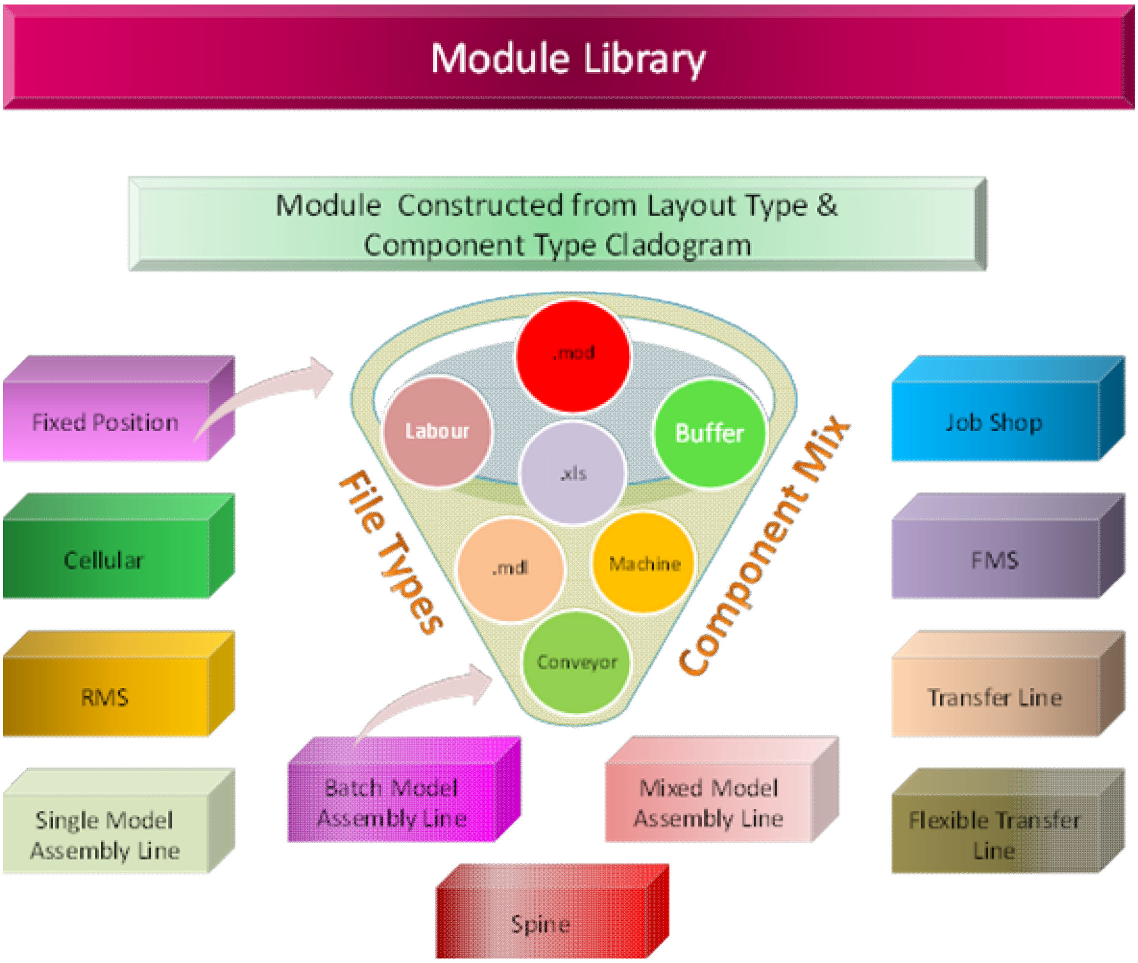
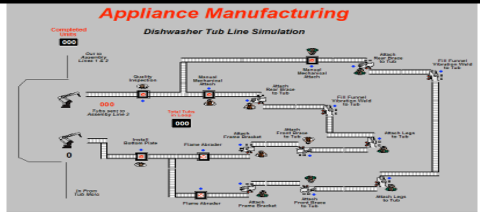
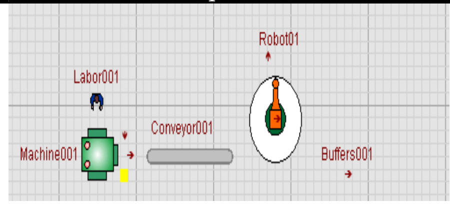
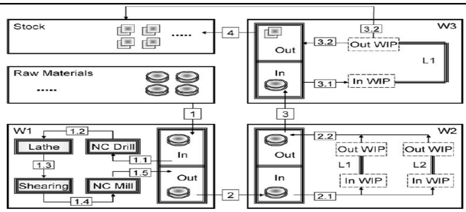
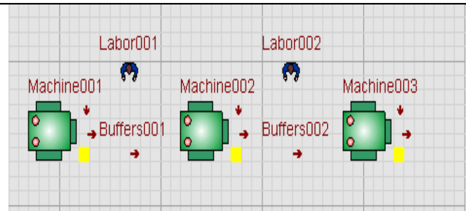
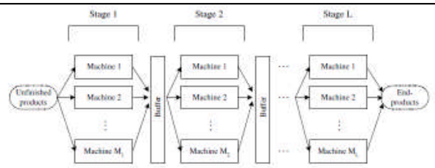
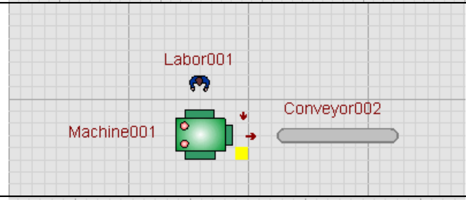
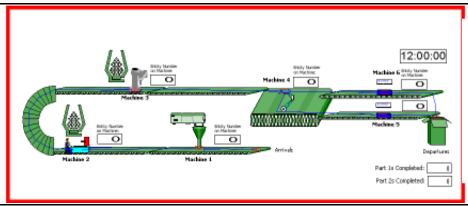


Figure 15: The module library

Table 10: The models collected from data and their Witness equivalents.

Author	Real World Model Taken From the Data Collected		Witness Equivalent Model	Components
Harrell & Gladwin (2007)		Assembly Line Machines, Conveyors, Buffers, Labour, Robots		Machine Conveyor Buffer Labour, Robot
Huang et al (2008)		Job Shop: Machines, Labour, Buffers		Machine Labour Buffer
Quadt & Kuhn (2006)	Fig. 1. Schematic view of a flexible flow line.	Flexible Flowline Machines, Conveyors, Labour		Machine Labour, Conveyor
Tavakoli et al (2008)		Conveying Network Machine, Buffers, Conveyors.		Machine Conveyor Labour, Buffer

6.4 Module Creation Using Cladistics

The difficulty in providing the most appropriate simulation template in order to speed up the development of manufacturing models is largely due to manufacturing systems, are not well categorised or classified. Previous work in generic template generation for simulation models has been solely based upon the physical layouts (e.g. assembly facilities, cellular layout) but not necessarily based upon the problems that a simulation study will address. For example, a typical problem in manufacturing to be solved using simulation is to identify the bottleneck, which usually leads to the identification of the appropriate buffer locations (and sizes) to overcome this bottleneck. Optimising buffer sizes and locations would also address the problems in minimisation of work-in-progress (WIP). From this example, it is apparent that the goal of a simulation model may evolve from tackling one problem to another. For this reason, a new method of developing simulation model templates is required, allowing simulation models to be generated based upon similarity of layout type and hence the similarity of the decisions to be made. Therefore, two models with completely different layouts may share the same model template because they also share similar problems. One of the possible ways to facilitate this is by applying a classification method.

Having successfully generated the cladogarm it is now necessary to use the information presented in this diagram to aid in the development of the template based modelling library. In order to make sense of the information the author undertook a comparison of the systems collected against how these potential systems could be built using the WITNESS simulation software package. This exercise identified the different configuration of components which were being used in real world situations and this information was used to develop the modules which would form the base of the template library. Module creation in this instance takes place by assembling information from various sources in order to generate a completed module. As the diagram below shows, information is read in from the cladogram and then the layout type is identified. The layout and components are then identified from the data matrix in table 7 and 8 and the witness equivalent components are obtained from table 10. The necessary logic is then added to complete the module. Figure 16 below details the process which has been used in order to construct a simulation module which is based on cladistics.

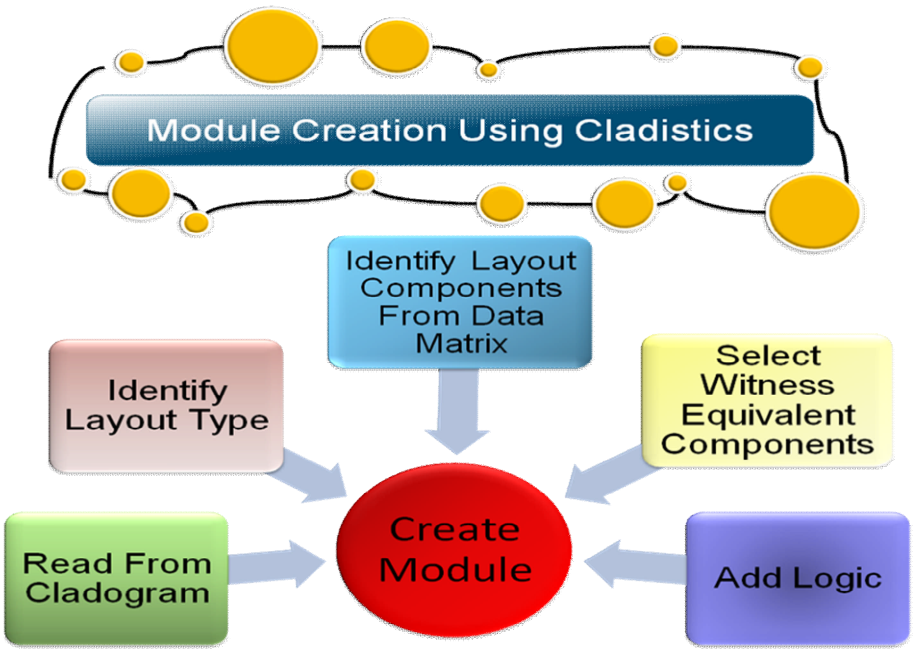


Figure 16: Module creation using cladistics

The process of constructing a module using the information generated in the cladogram can be seen as being a five stage process. The stages involved in this process shall now be discussed in greater detail;

Reading from the cladogram: The information collected and analysed on the various manufacturing types that exist produced a cladogram with 3 distinct groupings based on the manufacturer's volume of production. Manufacturing system types belonged to a low volume, a medium volume or a high volume production system. Analysis of the cladogram of component types showed that components used in the manufacturing environment started out as single elements but as time went by they evolved into various combined component types. Elements or (Variants) were all considered to be active and to be derived from a resource. The logic rules which were used for modelling single elements also evolved as the component type evolved with the rules becoming more complex as the functionality of the combined components increased. At this stage it is necessary to understand how the cladogram is read and how this information is interpreted as choosing the wrong components can lead to the wrong choice of layout type.

Identifying the layout type: It is now necessary to choose the required layout type. For e.g. a job shop or a cell or a spine layout. The choice of layouts total 11 and these have been identified from the information presented in chapter 4. Also when choosing the layout type it was necessary to refer back to the table of repeatable components which can be found in Appendix 1. The table referred to in appendix 1 contains information on all the possible combinations on components which may fall under the guise of a particular manufacturing system. For example an assembly line system may contain certain characteristics which makes it an assembly line, however not all assembly line systems may possess all of the indicated characteristics. Assembly line systems which possess some or most of these characteristics will still be considered as an assembly line. Therefore it is necessary to keep referring to the table shown in Appendix 1 as a means of verifying the type of layout chosen.

Identify the layout components from the data matrix: The information presented in chapter 5 of this report shows that it was necessary to construct a data matrix in order to generate the cladogram for both the layout type and the component type. The data matrix contains information regarding the mix of components and characteristics which can be attributed to a particular layout or component type. After identifying the layout type it was necessary to obtain the corresponding components for the layout chosen by simply reading the information presented in the data matrix. This gave a list of the components which are most likely to be used in a particular layout, and it is from this list that the module can start to be created. However it should be noted that this exercise simply lists the single component types. It does not identify the repeatable components. To obtain the repeatable component groups it was necessary to refer back to the table shown in Appendix 1. The identification of the single components was considered to be an important step in developing the module as the more complicated combination of components could all be built by combining the single elements.

Selecting the Witness equivalent components: After the process of identifying the components which are needed to construct the module it was necessary to understand how these components could be modelled using the simulation package used in this research i.e. Witness. As the systems and their components were all identified from real world cases, and all modelled using a number of different software packages it was necessary to build these systems using the witness software package so that a comparison could be undertaken. Constructing the model in witness helped to identify what components or group of components can be used in the software to replicate the systems identified. The equivalent Witness components identified can be found in the table shown in Appendix 1.

Adding Logic: This is the most crucial and also the most difficult part of the module building process. The modules created for use in RapidSim generator all need to possess the necessary logic needed for them to work. This means that the data stored in the module must contain information on part routing, input and output rules as well as the logic needed for model complexity and interconnectedness. The modules created need to be generic enough so that they can be used and reused in any possible layout but at the same time they must also be complex enough to foster repeatability. The way in which this problem was solved was through the use of variables. The use of variables in Witness allows the programming of modules without the need for specific names or logic commands. Saving the completed model using the "Save As" command in Witness does not alter the modules basic makeup allowing them to be reused once more. Since the RapidSim generator has been developed to run from Microsoft excel, the logic rules which are given to the module must coincide with the data which is stored in, and read from the excel tables. Also the variables which are used for programming the modules need to be stored in the main witness modelling page as this would be needed when the data transfer from excel to witness takes place. Figure 17 below shows a typical module which has been created using this approach. The information shown in the diagram is a representation of the logic which goes into the creation of every module which is to be used in the RapidSim modelling process.

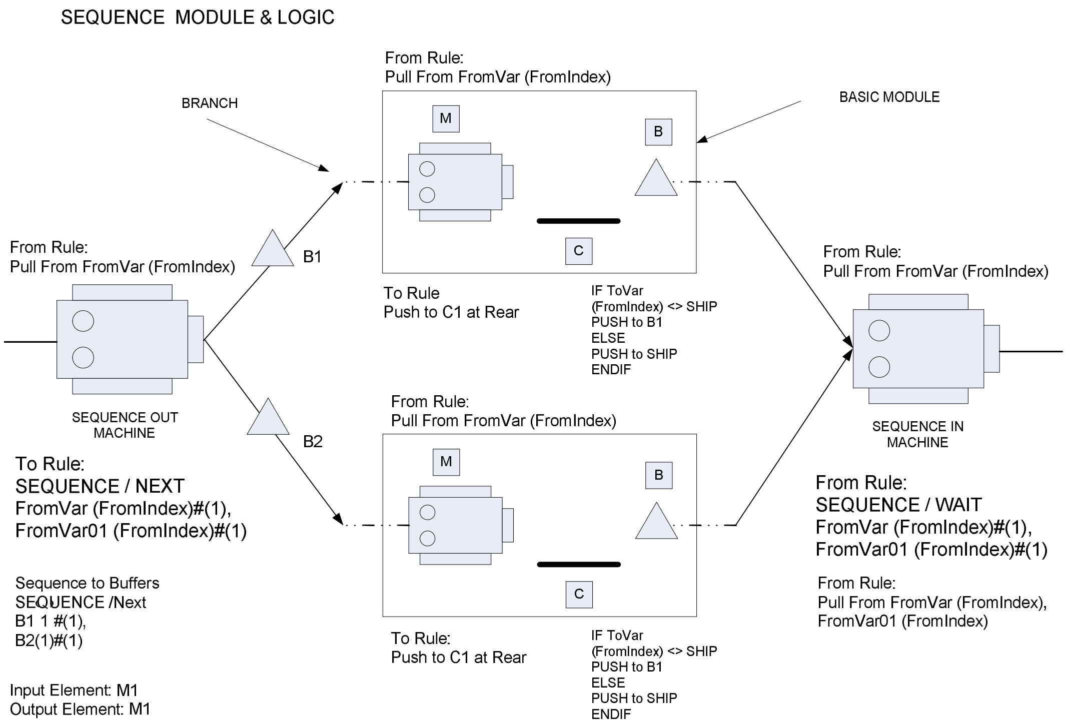


Figure 17: The module logic

6.5 Creating a Model Template

When we refer to the use of a template within the context of a simulation model, we are referring to a collection of user defined ready-to-use and re-usable building blocks which are created by programming, then-functionality, and interface and performance indicators in an appropriate simulation setting (Tjahjono2007). Evidence of templates being used in the context of simulation modelling can be seen from a study carried out by Pater and Teunisse in 1997. In this study they used simulation model components compiled in a model library to model the new railway cargo line connecting Rotterdam harbour with the Ruhr, the industrial estate in Germany. The model was used to study whether the capacity of the railway system would meet the requirements as set out in The Betuweroute capacity study of the Dutch rail network. Further evidence from Mukkamala et al. (2003) shows how the authors developed a domain-specific template for the automated assembly of printed circuit boards, based upon the work of Farrington et al. (1996). Winnell and Ladbrook (2004) developed a component-based simulation extension to an existing simulation tool to enable modelling of car engine assembly lines. Thesen (1990) developed a template-based simulator to analyse a material handling system for inspection and repair of workstations on a manufacturing shop floor. He used a template based simulator to implement a generic model over a broad class of situations. The generic model was used to describe parts and resources in independent templates that run on a simulation engine designed to incorporate random part routing with branching. Thesen also noted that "the usefulness of a template simulator depends on the appropriateness of the underlying model, the friendliness of the user interface, and the length of the resulting simulations" (Tjahjono 2007).

The solutions, adopted by researchers and industries, are “often customised to a very specific domain, for example tunnelling operations or railway lines, and were developed to fit within the framework or programming paradigm of a particular commercial simulation tool. The implication is that additional work is often required to customise the template, which often demands even more expertise in using a particular simulation tool. Second, the models generated using templates are generally limited to systems with regular patterns” (Tjahjono, 2007). Apart from interoperability difficulties, Benjamin et al., (2006) contended that "composability emerges as an important element in this process, since it is essential that the components, when put together fulfil certain specifications". Composability is defined as the “capability to select and assemble simulation components in various combinations into simulation systems to satisfy specific user requirements” (Petty and Weisel, 2003). Along the same line, Lei et al., (2007) commented "that in today’s world, simulation composability proves to be among the most challenging topics in the domain of simulation".

With technological advancements taking place on a frequent basis the concept of model reuse is becoming more widespread within the simulation modelling community. The concept of modellers developing reusable modules which can be used by themselves as well as others in varying fields of expertise is becoming a viable endeavour as it is seen as being beneficial in terms of cost and time reduction.

"The Reusable Simulation Model or (RSM) should meet certain specific requirements if it is to qualify as an RSM" (Lei et al., 2007). Towards modelling, "the RSM should be able to represent models which are described using multiple formalisms, as well as different domain specific concepts. It should also be able to support integration of models using the existing languages and tools by transformation and has to be independent of languages and platforms" (Lei et al., 2007). “The development of neutral, vendor-independent data formats for storing simulation models could greatly improve the accessibility of simulation technology to industry by enabling the sharing and re-use of models” (McLean and Leong, 2001). The creation of neutral simulation model formats or templates would be a great help to modellers in developing models which can be used and then re-used under different conditions in different industries. Having such templates would make simulation modelling more appealing to novice users. Widened use of simulation templates would foster increased creation and development of these templates which in turn can be turned into a viable business venture. McLean and Leong (2001) also suggest certain steps with this aim in mind, such as “Simulation study templates for addressing classes of simulation problems and building block modules of manufacturing system components to be used in the templates and libraries of simulation reference data sets”

6.6 Model Creation

“The development of neutral, vendor-independent data formats for storing simulation models could greatly improve the accessibility of simulation technology to industry by enabling the sharing and re-use of models” (McLean and Leong, 2001). Once the module building process has been completed the user can move ahead with developing the model templates. As the modules are made up of any number of components the scope for reproducing these components becomes quite vast. All of the modules are stored in a centralised file system or folder to facilitate easier and faster access to the information.

In witness the designer elements of the simulation system can be used to represent real world entities such as machines, buffers conveyors and labour, which can be both be described and displayed within the simulation modelling window. In order for these modules to be used within the model they firstly need to be saved as a designer element by combining or grouping the elements, and defining them as "designer branch" in the "parent box" of the simulation window. Secondly they need to be added to the tabbed section of the element window and saved for further use. The modules can then be customised for any particular application or process. And they can be directly introduced into the model using a "pick and position" method. However it should be noted that as this method works for the conventional model approach but it does not work for RapidSim. The modules are still stored in the witness model file as in the conventional method but they cannot be used in the same fashion. In the conventional approach these modeller could use the pick and drop method and then customise the model by adding the necessary logic inputs and outputs. As RapidSim uses a secondary data interface to drive the simulation engine the logic for the module is embedded into the interface’s programming and can only be transferred onto the module when the model is generated on the witness screen.

The information presented in figure 18 depicts the conceptual simulation model development where modules and data from an interface are added and assembled on the model template. Generic modules all contain the necessary information and functional requirements for them to operate. These modules are stored in a module library and they comprise the modelling components needed to construct the model. Data is transferred into the simulation software package via the use of Microsoft Excel to help with automatic model generation and to reduce the time taken for detailing all the components of the model. By combining the different modules with the data in excel the user is now able to create a model template. Creation of a simulation model takes place when the created templates are used either on their own or combined with other templates to build a simulation model.

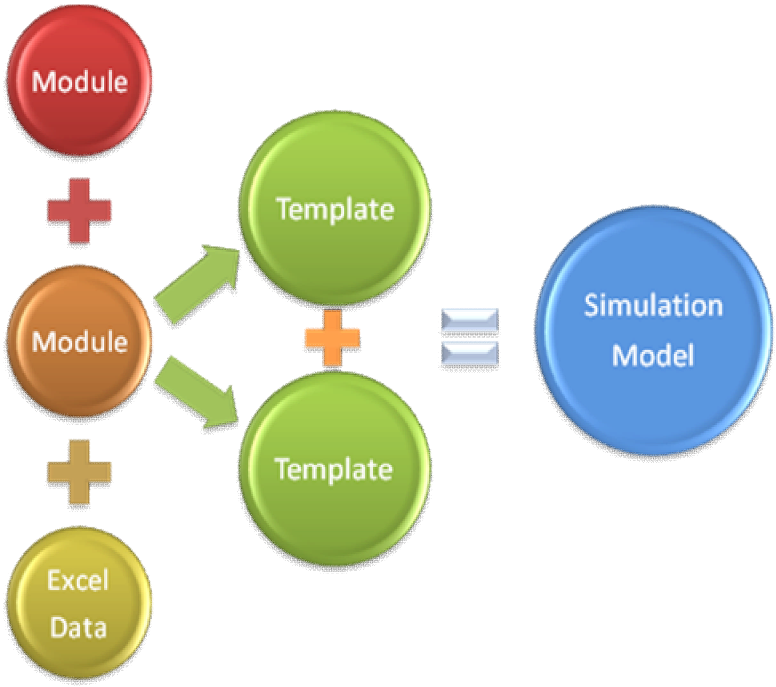


Figure 18: The conceptual model development

6.7 The Model Library

Each simulation product is unique with its own interface, with different capabilities to enact the evolution of the models over time and mechanism and tools to analyse and interpret the output from these models. It follows that the extent of complexity of the model building process itself and the sensitivity of the analysis tools also vary dramatically. This makes “the building, running, and analysing a simulation model to be a time consuming and error-prone process” (Son et al., 2000). The concept of independent neutral libraries which contain the simulation components, the completed modules and the model templates has been proposed as a solution to the above mentioned issues. In the context of this research the neutral library mentioned above refers to the collection of modules and templates which are designed for use and reuse in more than one particular layout type. "Unique modelling templates, such as an equipment simulation and supply chain simulation, etc. can help to further define these component models" (Son et al., 2000; Mertins et al., 1998).

In forming such a library the individual components each become “building blocks” or “modules” upon which the model can be developed. As the secondary user interface developed in Excel is used to drive the simulation engine it can be described as a model constructor and as such it can be used to generate a simulation model. The use of excel and the neutrally developed templates allows the modeller to create a simulation model that fulfils all the necessary requirements laid out in the commercial simulation package. The development of template based libraries help simplify the model building process and also "enables component based modelling, model reuse, and internet-based services, all of which could reduce the complexity and effort of simulation in manufacturing" (Son et al., 2000). Robinson et al., (2004), states that the development of these libraries “can benefit the simulation model reuse by allowing the users to select the components from a common point , thus reducing both time and cost when compared to those involved in developing a new model”. The repeated use and reuse of component located in the template library increases the modellers experience with these components and it also helps in providing additional testing and verification of the modules for future use. As a result of being reused, “library components are more reliable and less prone to faulty behaviour” (Robinson et al., (2004).

Mertins et al., (1998) argue that although "within different simulation systems mechanisms like templates, modules or classes such as Arena, M-Plant are already available, and reference models exist, which help to further improve these mechanisms". Due to their lack of compatibility these methodologies are specifically formulated for work with one specific simulator and as a result they cannot be used in other simulators. "The neutral template based library facilitates the reuse of simulation models from different simulators in different simulation scenarios" (Mertins et al., 2000). There is also the advantage that there is room for “distributed simulations between different enterprises without the necessity for these enterprises to use the same simulator” (Mertins et al., 2000). This library of modules can be stored in a relational database based on the principles of Ontology. The concept of Ontology has been described by Benjamin et al., (2006) "as a useful tool in the simulation modelling and analysis lifecycle especially in the problem analysis and conceptual model design phase. He discusses the advantages and challenges in the use of ontology in simulation modelling. Ontology development focuses on extracting the essential nature of the concepts in any domain and representing this knowledge in a structured manner" (Benjamin et al., 2006).

The main objective of building of a library is to store the created modules, templates and interface and to make these items easily available and retrievable for use in generating the simulation model. The library contains data storage entities that represent each of the identified manufacturing systems and it houses the Witness file that represents the template for the model, the module file which represents the building blocks for the model and user interface file for data input. These files are stored in *.mod, *.mdl and *.xls file formats as shown in figure 19. This library equips the modeller with a set of pre-developed templates, modules and an excel driven interface which could be used to assemble a model quickly. However, it must be noted that the assembled model may require some modifications in order to meet the requirements of the end user. The end user may need to modify the machine times, the cyclye times and the sequence percentages etc. so that the modules used operate within the specified parameters of the model constructed. The modules used in the model building process will all have varying levels of modifications needed. More on this will be highlighted in chapter 8 of this thesis.

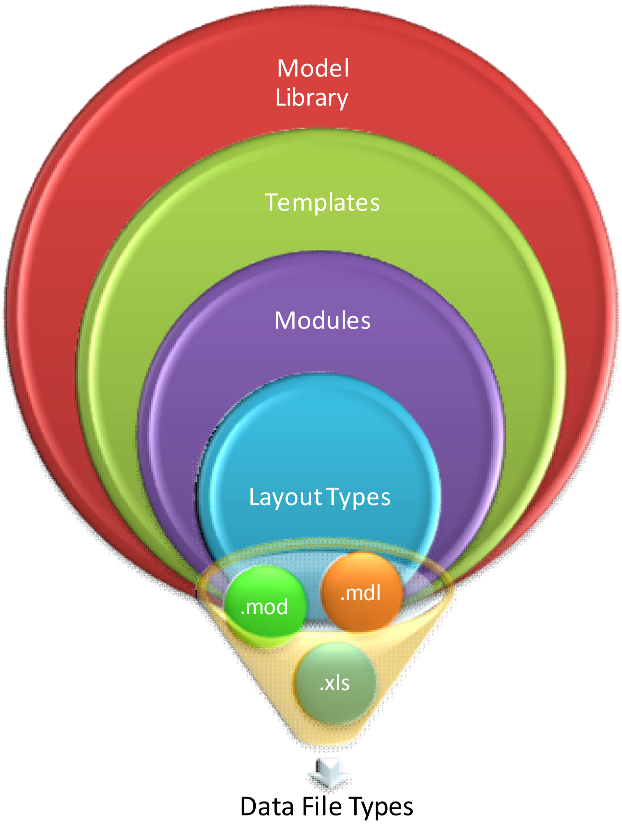


Figure 19: The model library

6.8 The RapidSim Interface

The RapidSim interface was developed with the aim of making simulation modelling faster and easier to use. The interface has been designed using Microsoft excel and it has been programmed using visual basic. The design of the interface is aimed at giving user's an easy approach to the selection and modelling of layout types.

6.8.1 RapidSim Dataflow

The RapidSim interface has been designed with the intention of guiding the user through a quick and smooth model building process. With this in mind the data flowing through the system is so as to make the model building process as smooth as possible. The following is a brief explanation of the RapidSim data flow as shown in Figure 21 below. The process of designing the interface begins with enabling the system macros which are embedded within the main excel modelling page. When this has been done the system is now ready to receive and execute the commands which have been programmed into the interface via visual basic. The first modelling window is based on the user’s volume of production selection. Within this window the user is given three possible choices as well as the choice of restarting the volume selection process at any time. Two of the volume selection choices prompts the user for an additional choice in the form of selecting a system type or a production type system. At any time the user is allowed to go back or restart the process.

Based on the user’s choice of layout type a pre-determined list of components is loaded when the main modelling window opens. The main modelling window also contains all the components which can be used in the construction of the model. The user is given the choice of working either from the list of pre-determined components, from the list of “all” components or from a combination of both. The user chooses the components needed for the model of if needed can go back to the volume selection window and restart the layout selection process. After selecting the model components the user needs to add data to the model by selecting the order of route inputs. Here the user can choose the order which the components will be replicated in the model. If the user is unsure of the order of route inputs or wants to reset the model they can use either the back button or the model reset button to restart the model building process. Once the route inputs have been selected the user is prompted to select and set the component position data and then create the model.

The dataflow for the RapidSim interface can be seen in figure 20 below and was designed after collaboration between the author, his supervisor and some end users. This collaboration was vital to the design of the user interface as it depicted the way in which the interface would operate. As the previous work done in the manufacturing system cladogram highlighted the three varying volumes of production this information was used to program the first user interface window. The information gathered from the component type cladograms was then used to program the second user interface window. Based on the user selection of volume type, the matching component types as highlighted from the cladogram would be loaded into the third modelling window as a list of pre-determined components. Within the main modelling window it was envisaged that the user was given the choice to use either using the pre-loaded components or selecting the components required from a populated field. It was also envisaged that the user be free to select the route inputs for the modules as well as the modules position in the modelling window before model creation could take place. More on how the interface works is detailed in the next section of this thesis.

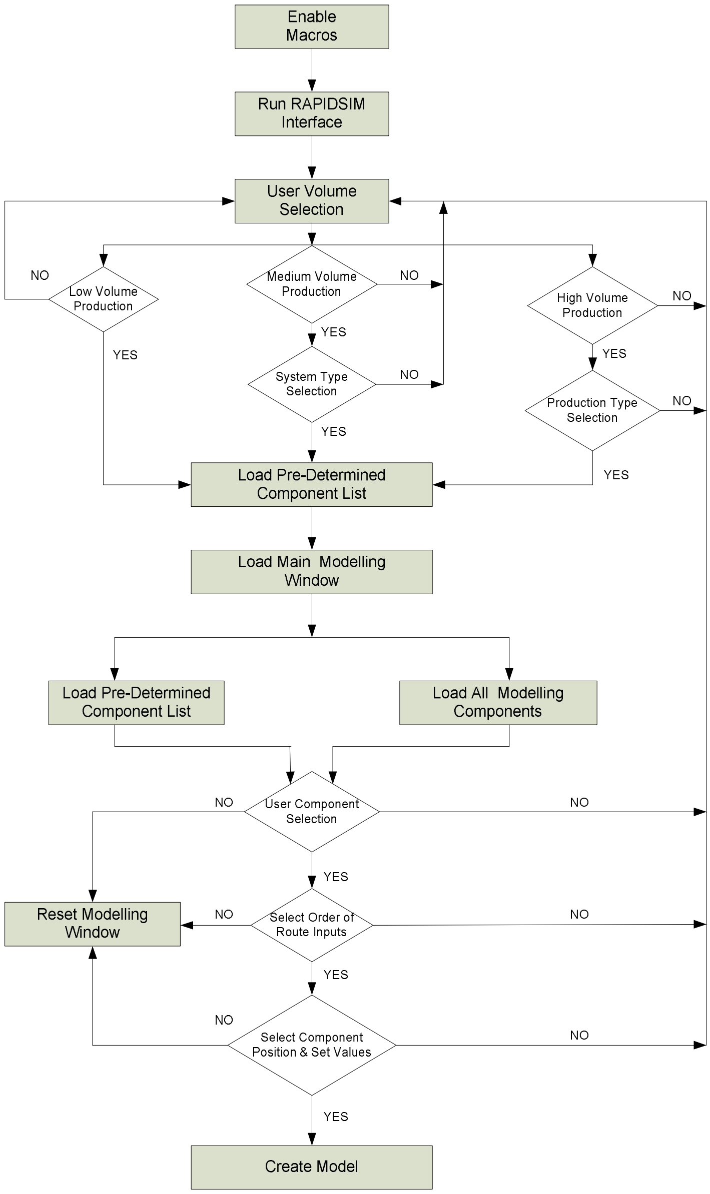


Figure 20: The RapidSim data flow

6.8.2 Working with RapidSim

Step 1:

In order to use the RapidSim Interface you need to open the corresponding Excel File, which in this case is the "ModuleDemo.xlsm". This can be found on the desktop in the folder named "Interface Docs".

Step 2:

Double click on the "ModuleDemo.xlsm" excel file to open it. When opened click on the options button. In the pop up window that opens, select enable this content and then click on OK to proceed. Figure 21 shows the displayed systems macro window.

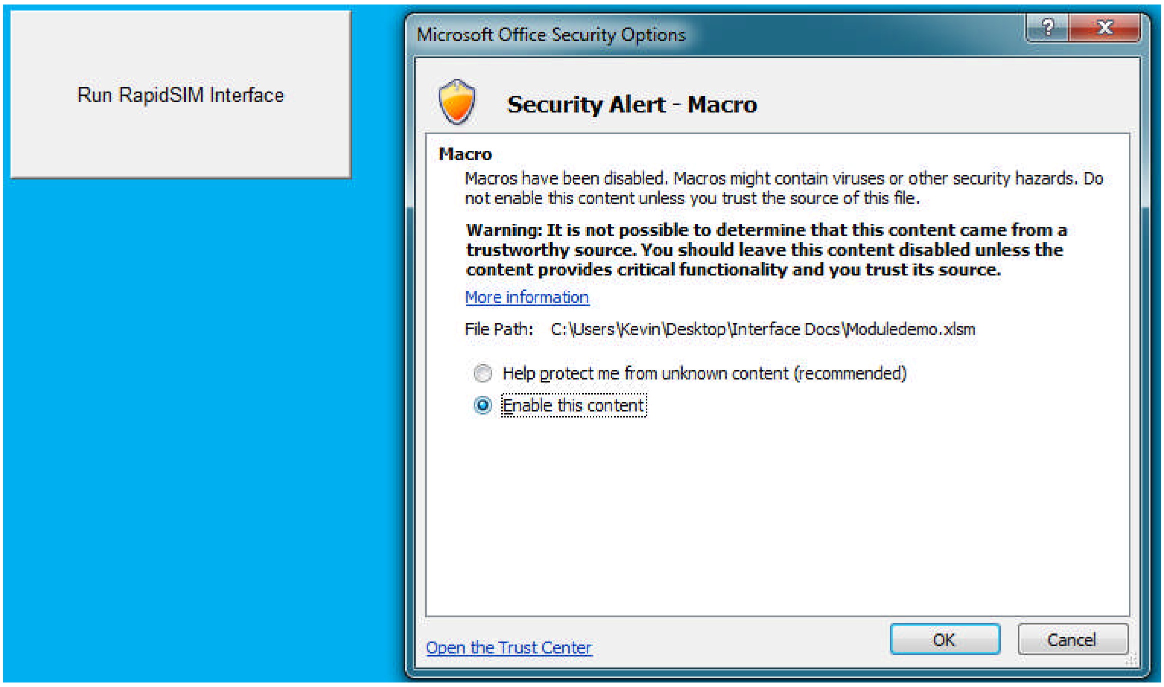


Figure 21: Enabling the system macro's

"Clicking on OK enables the macros's which are programmened in this workbook and it imparts full functionality to the interface".

Step 3

Click on the Run RapidSim Interface button. A new pop up window opens prompting you to select your volume of production (Figure 22) . This choice determines which type of manufacturing layout you may most likely be using. Select one of the three options provided, and then click on the next button to proceed with the model building process.

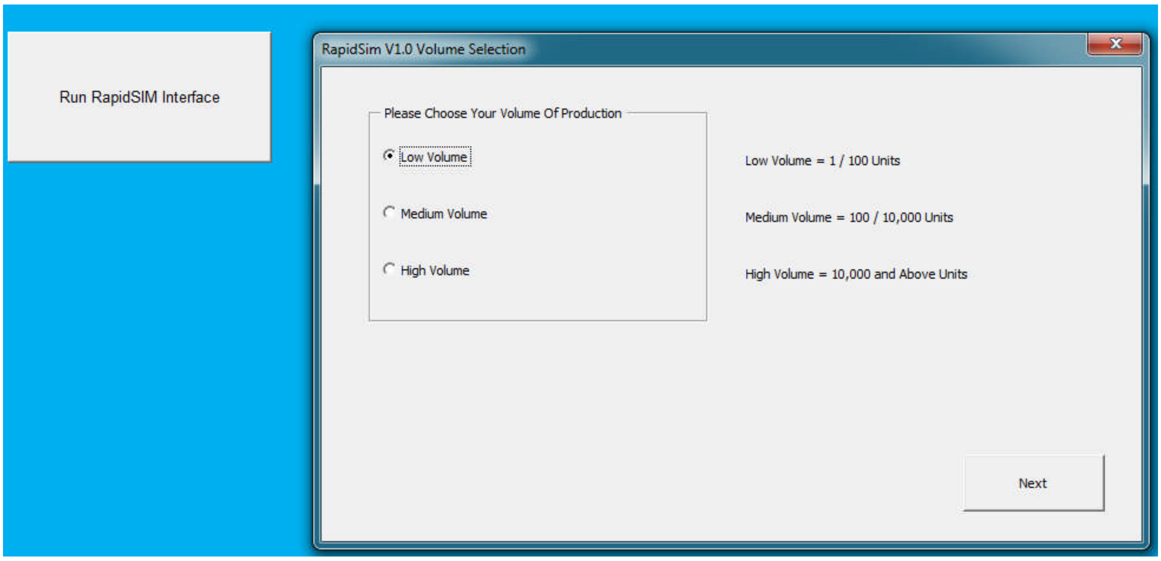


Figure 22: Volume selection

If low volume is selected you will proceed straight to the main interface window. However if medium or high volume Is chosen you will proceed to the System Selection and the Production type selection windows respectively (Figures 23 and 24). The modules which have been identified from the cladogram as belonging to these layout types will be loaded automatically into the List Box 1 (Components based on layout choice) window. Clicking on the next button in either of these two frames will take you to the main modeling window.

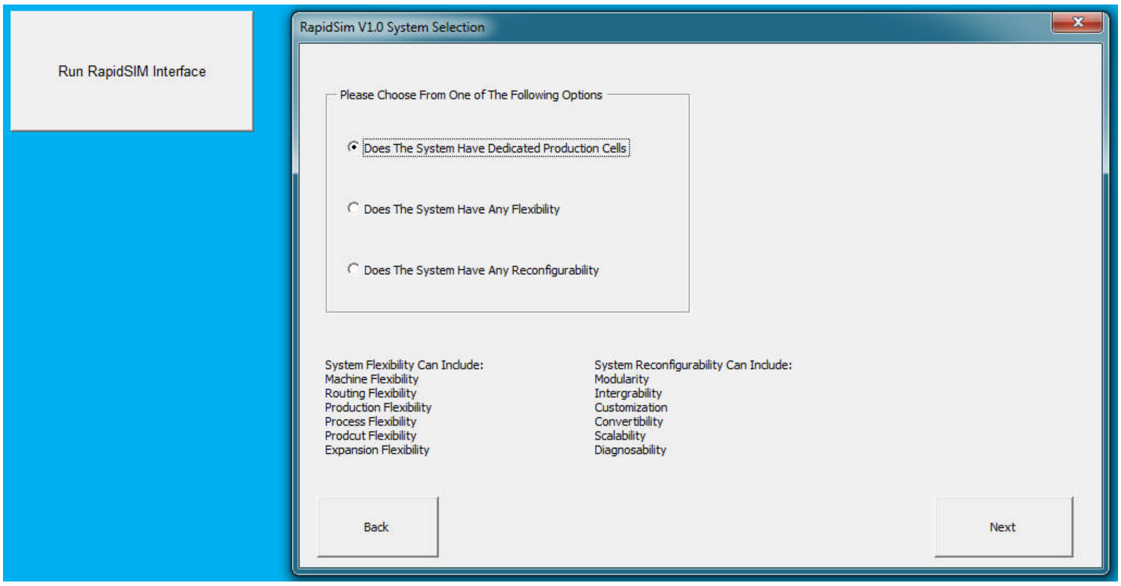


Figure 23: The System selection window

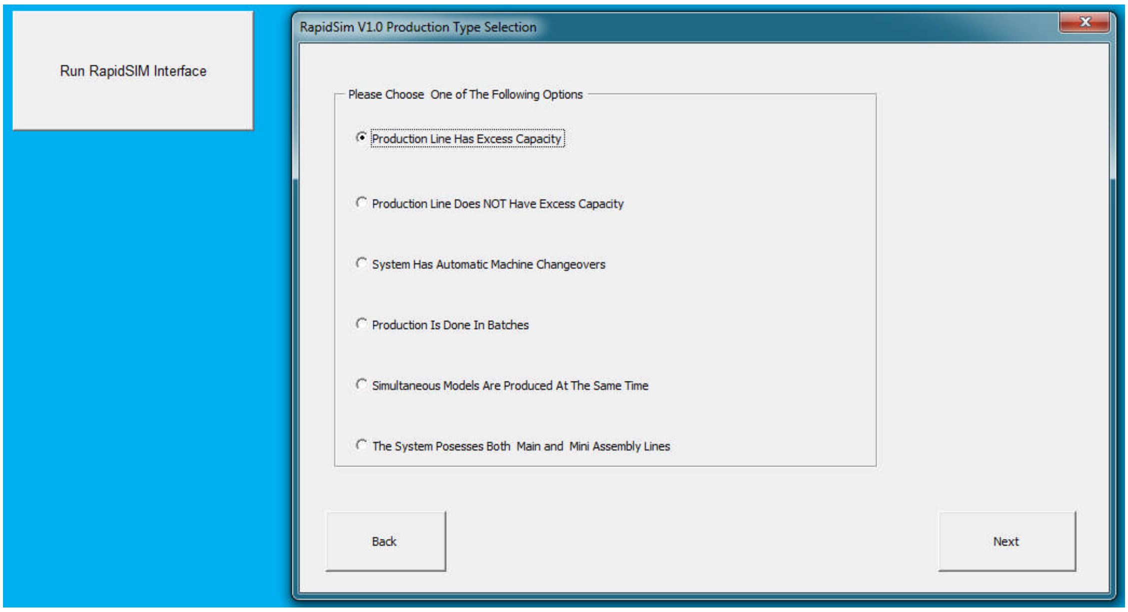


Figure 24: The Production type selection window

Step 4: The Main Interface .

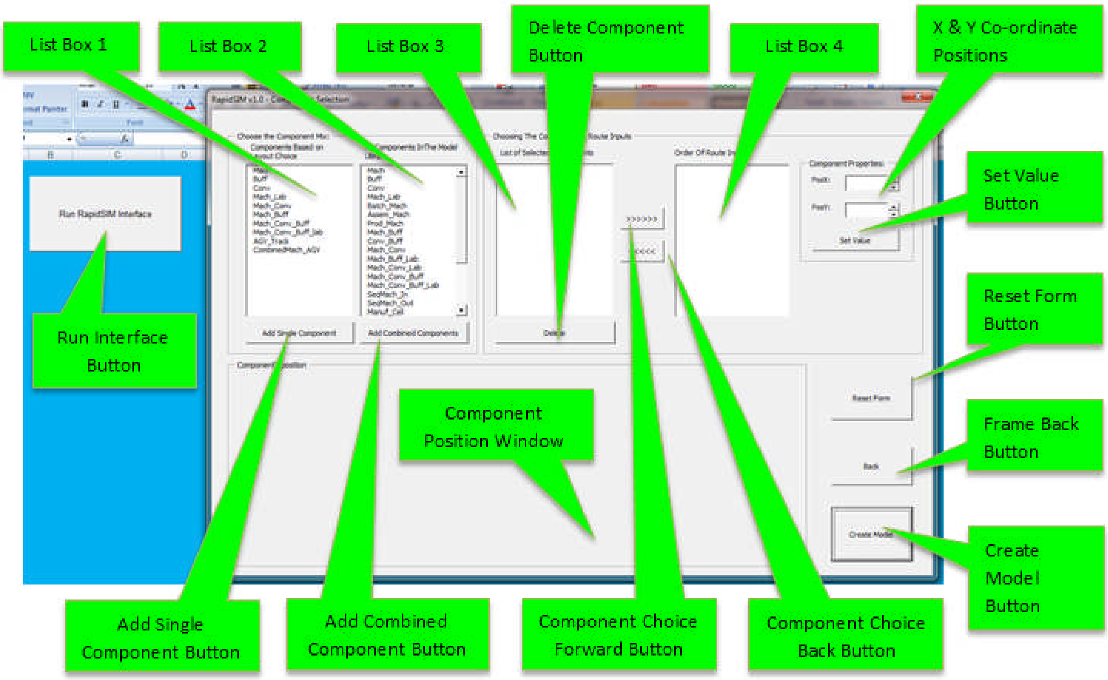


Figure 25: The main interface window

About the interface

The following information relates to the various aspects of the interface design and their usage. The main interface is displayed in figure 25 above.

List Box 1 (Components based on layout choice): This list box displays the pre-loaded modules which best represent the user's choice in steps 1 to 3. These components can be added to the model by highlighting them one at a time and then clicking on the "Add Single Component" button. Any component can be added more than once by highlighting that component and clicking on the "Add Single Component" button repeatedly. The added component/components will be displayed in list box 3.

List Box 2 (All components in the model library): This list box displays all the modules which can be used in the model building process. These components can be added to the model by highlighting them one at a time and then clicking on the "Add Combined Component" button. Any component can be added more than once by highlighting that component and clicking on the “Add Single Component” button repeatedly. The added component/components will be displayed in list box 3.

List Box 3 (List of selected components): This box displays the choice of modules selected from list box 1 and 2. These components are displayed randomly and components can be deleted from the list by highlighting the chosen component and then clicking on the “Delete” button.

Forward Button: This button is used to select your choice of route inputs for the part. Selecting the component and then clicking on the forward button moves the selection into list box 4, which details the order of route inputs according to the order of the components selected.

Back Button: This button is used to de-select components from the order of route inputs which have been placed in list box 4. Selecting the component and clicking on the back button removes the component from order of route inputs and places it back into list box 3.

List box 4 (Order of route inputs): This list box displays the chosen components and the order of their inputs for the simulation model based on the users choice. Components can be added and removed from this field by using the forward and back buttons respectively.

Set Value Button: After the order of route inputs have been decided the set value button is used to set the display position of the component on the Witness screen when the model is created.

Component Position Window: This window displays the co-ordinate positions which have been set for the component using the set value button. This window allows the user to position the icon wherever they choose. The position of the icon in this window depicts the position the icon will appear when it is replicated onto the Witness screen.

Reset Form Button: This button is used to reset all user selections in the interface.

The Back Button: Clicking on this button takes you back to the volume selection window to restart the model building process.

The Create Model Button: Clicking on this button transfers the selections made in the interface onto Witness.

6.8.3 Model and Module Repetition

The Excel driven user interface uses the Macros which are enabled within the software's developer tab to transfer data between Excel and Witness through the use of visual basic scripting. Visual basic scripting is a scripting language which has been developed by Microsoft and which has been modeled on its more widely known counterpart Visual Basic. VBS has been developed in order to facilitate a language which fosters fast interpretations for persons working in the Microsoft environment and it use the Component Object Model to gain access to elements within the environment it is being used. An e.g. of this would be the File System Object (FSO) which is used to create, read, update and delete files. The macro is specifically programmed to check on the status of the model being developed and if the macro detects that the model is in the "run mode" the macro pauses the model and transfers the data onto the model window in Witness. This feature gives users the ability to change the data used in the model even when the model is operating in "run time". The use of macro for transferring data from a Microsoft Excel file shows how the application of a desktop resource can facilitate making simulation tools easier to use as most persons are familiar with some or all of the functionalities of Microsoft Excel.

Following the systematic approach mentioned a manufacturing layout can be generated quickly and efficiently making the use of the simulation tool easier to the end user. It should be noted that the application of this methodology positively disrupts the previous ideology regarding conventional modelling techniques as the modeller does not need to possess any in depth knowledge about the simulation modelling process to create models using this approach. This approach reduces the level of expertise needed to create a simulation model thereby making it easier for both simulation and non simulation experts to use simulation based modelling. However it should be noted that the modeller needs to possess some basic simulation modelling knowledge which is important at the conceptual development stage of the simulation model. The modeller also needs to possess knowledge of working with the modules in order to generate the model necessary for their respective needs. The modules which have been created are all embedded within the witness demo file, including the designer elements and all the necessary variables which are needed in order to generate the model. When the information is transferred into witness, the witness command language (WCL) reads this and recreates the model based on this information.

One of the main advantages of the RapidSim interface is in its ability to drive or control the Witness simulation package. What this basically means is that the Witness model file (.mod file) does need to be open when the interface is being used. All the model building activity takes place on the excel screen and not on the Witness model page. After the components have been positioned and their values set using the Component Position Window (*the position of the icon in this window depicts the position the icon will appear when it is replicated onto the Witness screen*) and all the necessary information has been filled in on the interface, the end user needs to click the “Create Model” button to execute their choices. The choices made in the interface shows up as a replicated model in witness. However, before this can happen the user is guided to one last selection window which prompts them to select the Witness .mod file they wish to transfer the data to from the interface. The main reason behind this feature is ensure that the data is transferred to the correct Witness file every time a new model is built. Figure 26 below shows the window prompting the user to select the appropriate witness.mod file.

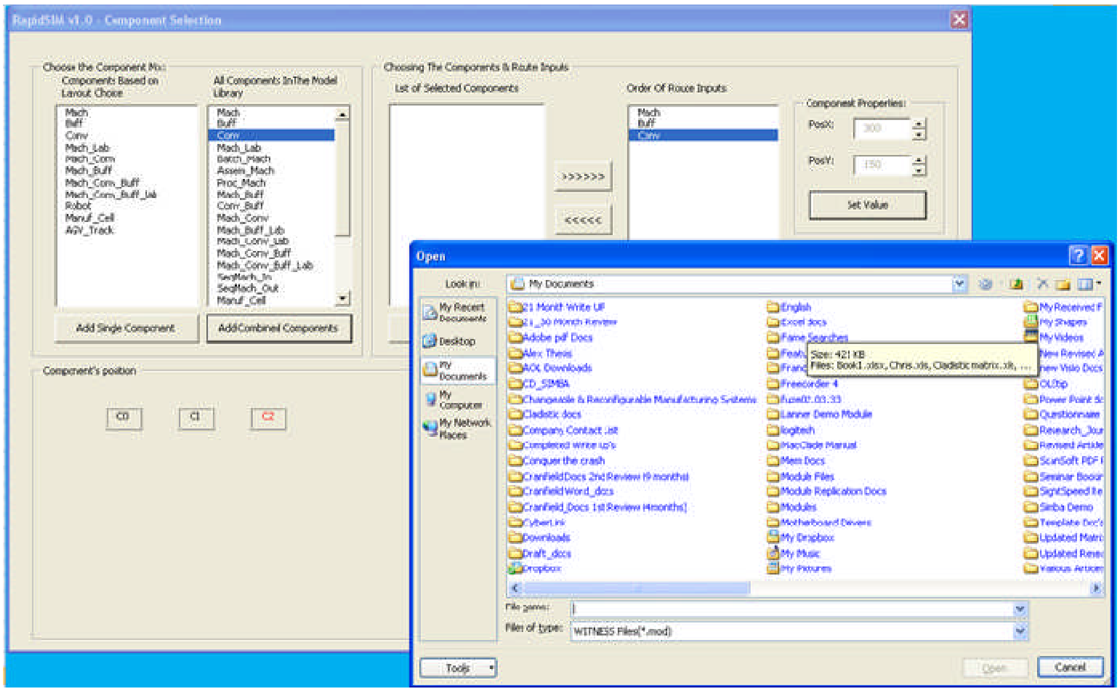


Figure 26: The file selection window

On selecting the appropriate file the data is then transferred into the witness simulation package resulting in a completed, interconnected and ready to use simulation model. However the benefits of using RapidSim do not end there. One of the most important features of RapidSim is in its ability to capture and record statistical data about the model developed. Using the conventional approach to modelling, performance measures which capture statistics such as the average lead time, the number of work in progress and the average machine utilisation are not easy to document, and for users who are unfamiliar with Witness it can prove to be a very difficult task. However this is not the case with the RapidSim approach. Statistics regarding the average lead time, the number of work in progress and the average machine utilisation is captured for the user in the form of graphs and pie charts in the modelling window. The user simply needs to read these values in order to obtain a statistical report. Figures 27 and 28 below shows the statistical capture tools which are embedded into the witness modelling file.

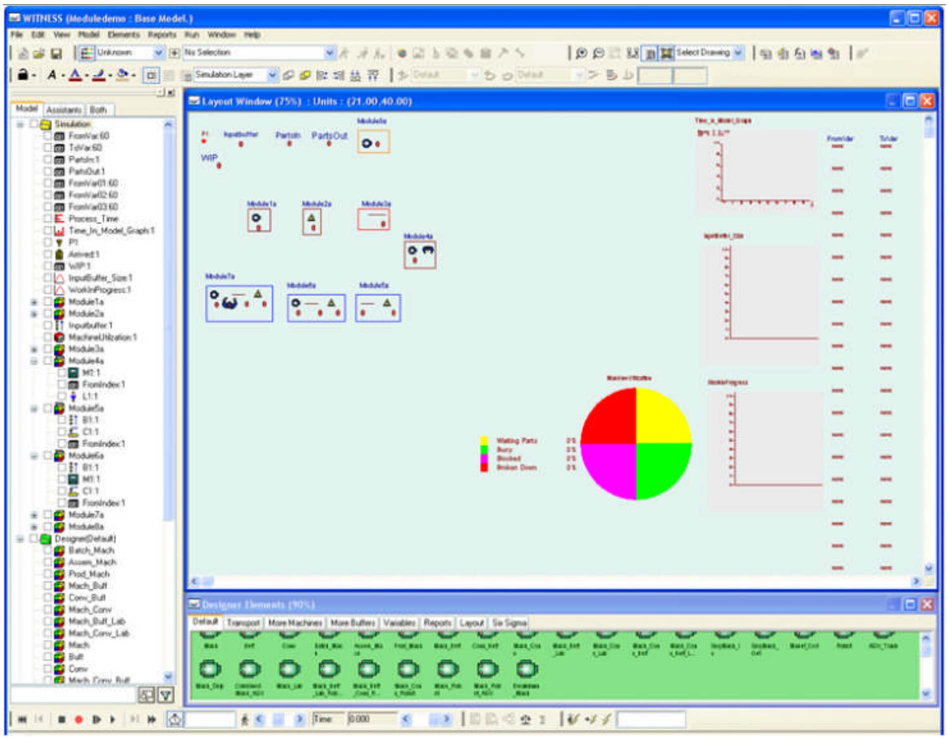


Figure 27: The modelling window showing the statistical tools before model is run

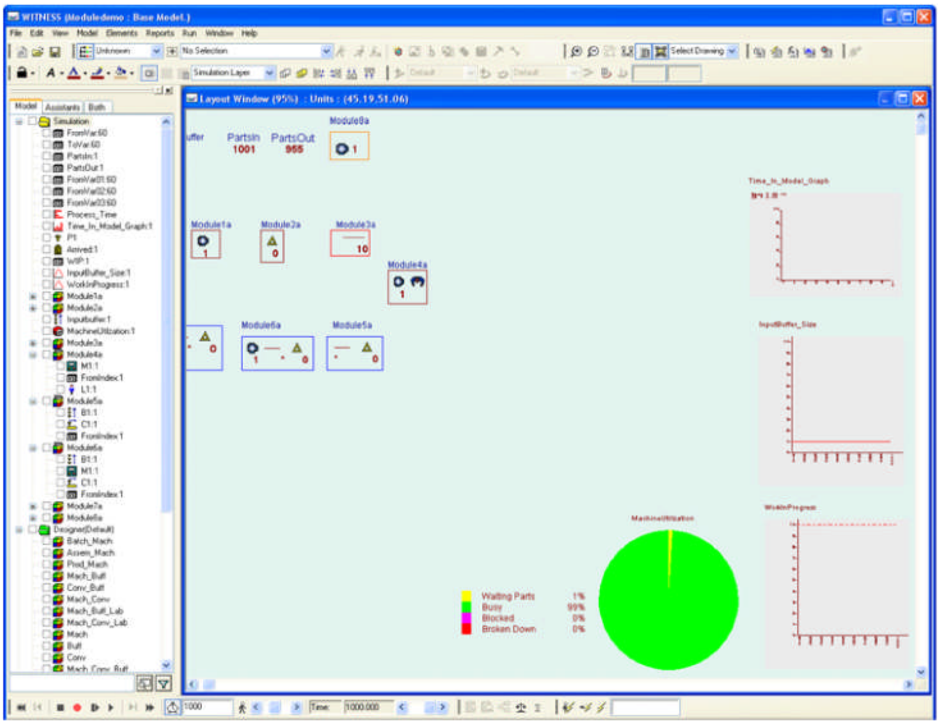


Figure 28: The modelling window showing the statistical tools after model is run

6.9 Summary

A simulation module can be quickly created if it can be assembled by adding the building blocks (modules) in a model template. In developing a template based library the individual components each become “building blocks” or “modules” upon which the model can be developed. As the secondary user interface developed in Excel is used to drive the simulation engine it can be described as a model constructor and as such it can be used to generate a simulation model. The use of excel and the neutrally developed templates allows the modeller to create a simulation model that fulfils all the necessary requirements laid out in the commercial simulation package and it also helps increase the speed by which models can be built.

Chapter 7

Validation of the Proposed Template Based Modelling Approach

7 VALIDATION OF THE PROPOSED TEMPLATE BASED MODELLING APPROACH

7.1 Introduction

The overall aim of this research is to investigate a new method of rapid simulation models development using template and model pattern based upon cladistics and evolutionary analysis. The work presented in this chapter details the work carried out in validating the design of the template based library and the external user interface. It includes the case studies which have been used to test the interface as well as the results which were obtained from those exercises.

As this chapter progresses the methodology used in designing, building and testing the software interface as well as the results obtained will be discussed in the subsequent sections.

7.2 Validation Methodology

When dealing with the validation process for any new software program or any additions to that program such as an external interface it is always worthwhile understanding some of the concepts that are associated within the validation process. The following is a list of definitions that are associated with the validation process;

Computer system. A group of hardware components which are physically connected and associated with software which has been designed and assemble to carry out a specified function or group of functions. *(GAMP Guide. Validation of Automated Systems in Pharmaceutical Manufacture. Version: V3.0, March 1998)*

Software. A collection of programmable logic, executable routines and subroutines which are used to control the operational parameters of a computerised system.

Standard or configurable software packages. These software packages exist as commercially available products which can be used to create customized software solutions (e.g. spread sheets). The applications which are created by these packages should always be validated.

Custom built or bespoke systems. The software solutions to some computing needs can either be custom built or they can be specifically ordered for the end user. These systems should be validated in accordance to the validation plan for a full life cycle model.

Testing. This is defined as the process of evaluating a system or system components either manually or through automation to verify that it / they satisfies all necessary requirements and it can also be used as a means of identifying differences between expected and actual results.

Verification. This term refers to the process that is used to confirm that the output associated with the development phases of the software meets the inputs requirements for that phase.

Validation. This is defined as establishing through the use of objectivity and objective evidence that all of the software requirements have been implemented completely and correctly and that they are fully traceable to the system requirements.

As the interface which has been developed is built through Microsoft excel it is considered as being a self-developed software product and as such it requires full software validation. The software package itself does not require validation but additions which are made to the package should always be fully tested and approved before use. It should be noted that spread sheets which are used in excel are considered to be programs since they have a wide-open user interface and as such can become very vulnerable to unintentional changes. As the software developed is built through the use of Excel and Microsoft Visual Basic for Applications it is important that this vulnerability be understood.

With the development of any new software product it is sometimes necessary to test parts of the software as the development process is taking place. The tests performed should be recorded so that there is documented evidence that development is proceeding as scheduled. For any software product the main reason behind a validation exercise is to establish through the use of objective evidence that all of the software requirements have been implemented completely and correctly and that they are fully traceable to the system requirements. It also aims to establish that the software performs adequately in its expected surroundings. The final validation exercise is seen as a combination of all the individual validation exercises which have taken place during the software development phase and it is used to form the completed computer system. The validation methodology that has been followed in the design, implementation, testing and execution of the RapidSim interface is shown in figure 29 below. The methodology follows a six stage process which shall be discussed as this section proceeds

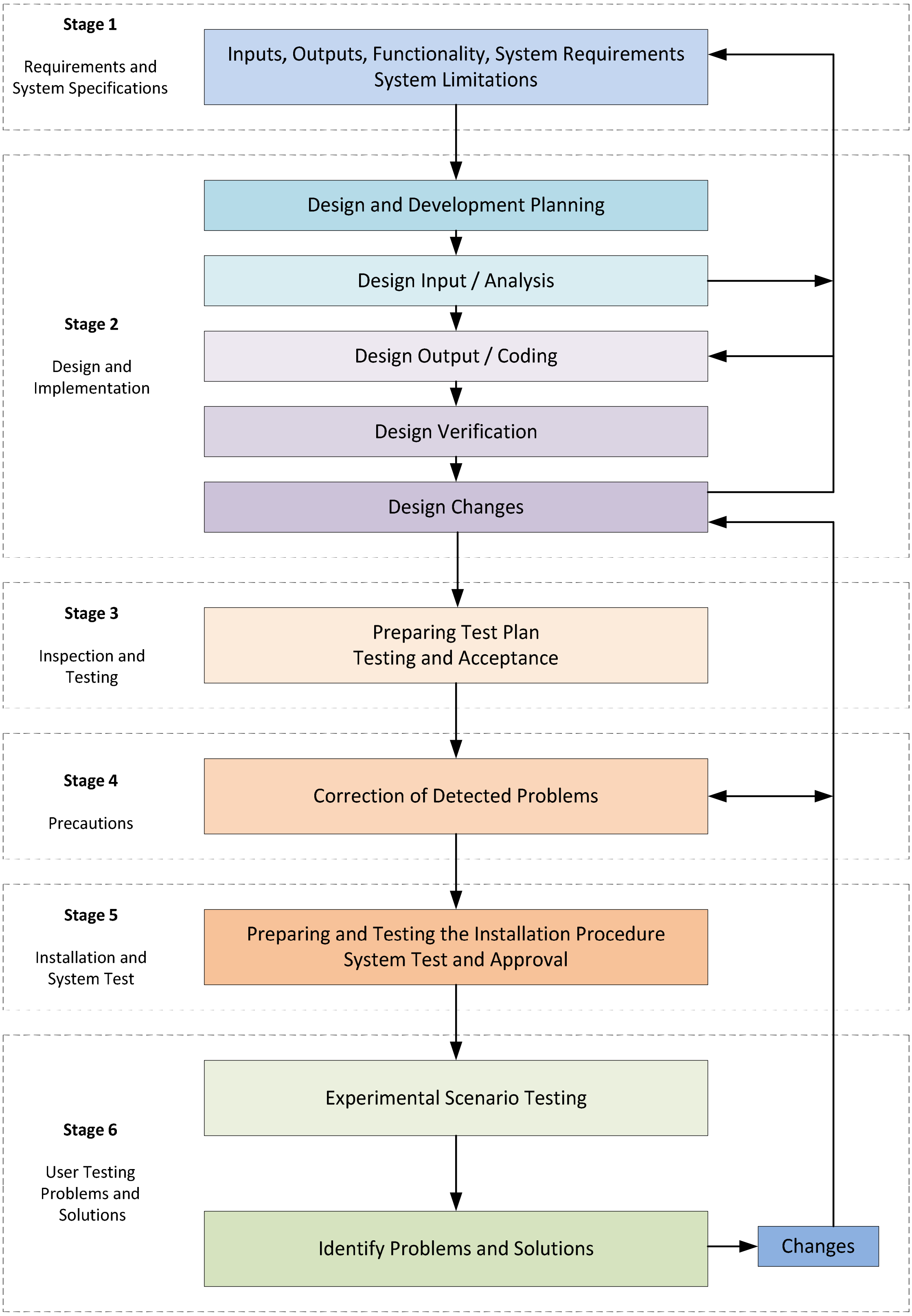


Figure 29: The Validation Methodology

Stage 1 Requirements & specifications:

The requirements that are agreed upon describe the software product to be designed and it also forms the basis for the software development and validation process. In the case of this research the software requirements specified the design of an external based interface developed in either Microsoft excel or through the use of Visual basic programming that can be used to drive the Witness simulation engine. The functional requirements for the witness model such as icon position, component interconnectivity, component repeatability, component modification, statistical data capture etc. were also proposed. The software's interaction with the template based modelling library was also taken into consideration. The inputs (modules) and output (completed model) for the interface were detailed as well as the software's perceived functionality, traceability and limitations. The user choice of manufacturing layouts and components as well as the associated modelling challenges of designing a generic and repetitive modelling tool were proposed. As the interface was designed through excel it could be prone to erroneous input and unspecified changes. Special requirements regarding input protection and changes were specified as well as the requirements that the spread sheet be based on templates and not on old or modified spread sheets.

Stage 2: Design & implementation:

Due to the size and complexity of designing the external based interface this process was limited to inputs from only three persons who were directly connected to the research project. Design and redesign of the interface was done after extensive collaboration between the individuals involved. This stage was sub divided into several smaller more manageable sections so as to focus on more specific development activities and tasks. Completion of each sub – stage in a sequential manner was necessary before proceeding to the next stage. The activities carried out in these stages took the form of design and development planning, design input, design output, implementation and compilation of the coding, interface version identification, dynamic testing, design verification and identification of possible changes to the interface design. As the coding language used to program commands into the interface was a generic version of Microsoft Visual Basic it was necessary to test the coding structure on several different occasions as commands created in visual basic needed modification in order to work. Also it should be noted that the Witness software uses its own programming language called witness command language (WCL) which has its own programmable routines, sub routines and language. As the interface was designed through the use of visual basic for application it was necessary to translate part of the WCL language into visual basic format in order to foster communication and data transfer between the two systems.

Stage 3: Inspection & testing:

At this stage the planned inspection and testing of the software is carried out and the results documented in a test plan. The extent to which this test is carried out depends on the requirements which have been stated in stage 1. The test covers all aspects of the approach taken, the level of complexity involved, and the intended use of the program. At this time it is necessary to examine the data coding structure to ensure the rules of good programming practice are being followed. The test plan covered all aspects of what needs to be tested, what is expected of the tests and how the testing is to be done. It also contained details about what tests were done, the results obtained and if the results were approved. The following is a list of test specifications which have been recommended by Torp (2003-2004) and which were followed during the validation process.

Test objectives: Description of the test in terms of what, why, and how

Relevancy of tests: Relative to objectives and required operational usage

Scope of tests: In terms of coverage, volumes, and system complexity

Levels of tests: Module test, integration test, and system acceptance test

Types of tests: Input, functionality, boundary, performance, and usability

Sequence of tests: Test cases, test procedures, test data and expected results

Configuration tests: Platform, network, and integration with other systems

Calculations tests: To confirm that known inputs lead to expected outputs

Regression tests: To ensure that changes do not cause new errors

Traceability tests: To ensure that critical events during use are recorded and traceable

Special concerns: Testability, analysis, stress, repeatability, and safety

Acceptance criteria: When is the testing completed and accepted

Action if errors: What to do if errors are observed

Follow-up of test: How to follow up the testing

Result of testing: To approve or disapprove the testing

Stage 4: Correction of detected problems:

After completion of the software test and verification of the results it was necessary to fix any problems which were detected with the interface design and with its programming language. As programming between Microsoft visual basic and the witness command language was not straight forward it was necessary to re-examine the interface coding structure for any highlighted problems. Problems relating to the aesthetic layout and data flow of the interface were corrected at this stage of the process. As the interface was designed using a third party software environment, namely excel and VBA, it was worth noting that some undesirable, inappropriate, or anomalous operating conditions may exist. In the instances where these did indeed exist every effort was made to avoid these situations by working around the problem. The steps taken to work around these situations were also verified and tested before proceeding to the next phase of the validation process. Precautionary steps in the form of information message boxes were also used as a means of solving discrepancies between the way the software should operate and the way it actually does. Message boxes were used in the first two frames of the interface to guide the user through their selection of inputs, thus minimizing possible mistakes.

Stage 5: Installation and system test:

The extent of the testing done at this stage is dependent on the end use of the product as well as the testing possibilities that are available. For e.g. the user could conduct a small test as specified by the guidelines set aside in the validation plan. This however was not the case for this research as a full blown test of the interface was needed. In order to demonstrate the flexibility, speed and robustness of the interface as compared to the conventional model building approach. As the main aim of this interface design and the research process was the reduction in model building time it was decided that two test scenarios or case studies would be developed and that these scenarios would cover the expected use of the product. It was decided that the control scenario for the tests be scenario A, which is the manually constructed simulation model, whilst scenario B would contain the independent variable, that being the RapidSim interface. The case studies would contain the same exercises on building, linking and running a simulation model as well as exercises on rearranging the model, bypassing elements and measurement of the key performance indicators such as work in progress, average lead time and the machine utilization. The time taken by participants to complete both exercises would be documented, as well as the participant's feedback as to how the interface performed. Details of both the scenarios used in testing the interface can be found in the next section (7.3) of this report. Also it should be noted that as the program developed was confined to only the machine used by the developer a full blown installation test was not carried out. However the software was successfully installed on 3 separate machines to verify that it could be used within a networked environment.

Stage 6: User testing / problems and solutions:

After deciding on the testing scenario for the interface it was necessary to carry out the tests as specified in the case studies detailed in section 7.4 of this report. As the interface was designed for use by both simulation and non simulation based users it was important that a mix of these persons be involved in the testing of the interface. The testing was conducted over a period of two weeks and was made up of participants with varied levels of simulation modelling skills. Testing of the model allowed for user feedback which was then used in regard to decisions about changes to the interface design and the software revalidation. User feedback from this stage also identified any problems or glitches that occurred, prompting a solution to the problem. Feedback was also documented as to improve the overall performance of the interface.

7.3 Research Instruments

When dealing with the collection of empirical data it is necessary for those undertaking the research to employ one or more research tools or instruments to aid in the data collection process. For the purpose of this research a short questionnaire has been used in addition to the proposed case studies to evaluate the effectiveness of the proposed RapidSim user interface.

According to Brown (2001) a questionnaire can be defined as "*any written instruments that present respondents with a series of questions or statements to which they are to react either by writing out their answers or selecting from among existing answers*". Questionnaires can also be viewed as a set of systematically structured questions which are used by researchers in order to obtain vital information from respondents. It is the main data collection method in surveys and yield to quantitative data. Also, due to provision for open endedness, the instrument may be used to generate qualitative and exploratory data (Dornyei 2007).

As a questionnaire is made up of numerous items or questions, any one or more of these items can be used to measure the outcome of a proposed scenario. For this particular research project the questionnaire items have been selected from pre-existing research instruments that are valid and reliable, or formulated where necessary to suite the RapidSim interface application.

In order to simplify the questionnaire the rapid modelling application which is being evaluated has been referred to as "the interface" throughout the exercise. The majority of questions in the research instrument have been designed for use with the Likert-type scale. The Likert-type scale was invented by psychologist Rensis Likert and it is the most commonly used approach to scaling responses in research employing the use of questionnaire and survey instruments. In this instance the answers are fixed between 1 to 5, with 1 being “strongly disagree, difficult or slow” and 5 being “strongly agree, fast or easy”. Nielsen writing in (1997) recommended that researchers avoid using too many questions or questions which may be hard to understand, so as to avoid confusing or irritating respondents. With this in mind a small set of questions which have been chosen from the literature as well as formulated by the author will be used in this research questionnaire.

For the purposes of this research one research instrument or questionnaire was developed to test the users overall perception of using the RapidSim interface. The questionnaire was split into the following three sections:

Pre-usability: The questions asked in the first section of the questionnaire were geared towards collecting background information on the participants, i.e. the length of time participants has been using the software, in which environment the software was used.

Usability: As the questionnaire was based on the outcome of the case studies, scenarios containing seven tasks were devised to test the usability or ease of use of the applications. The user would complete each task and answer some quantitative questions on the scenario ease of use based on their perceptions. The seven tasks were devised such that they were of differing levels of difficulty.

Post-usability: A free form space was also allocated for the participant to write down their impressions and comments.

7.3.1 Perceived usage of Witness

The Witness usage items are listed in table 11 below,

The rapid modelling application built for this project has been developed for use by both novice and experienced simulation users. With this in mind it was necessary to establish the respondent’s exposure to, and usage of, the Witness simulation modelling software. Item 1 (*Time spent using Witness*) is selected because exposure to witness is seen as a key element of the case studies used and it also helps in differentiating between novice and experienced users. Items 2, 3 and 4 (*During lectures only, During group projects* *and During thesis projects*) are used to identify where and to what level the user has been exposed to using Witness software at university. Finally item 5 (*Before coming to Cranfield University*) is chosen to establish if the respondent was exposed to witness outside of university and in the workplace.

Table 11: Perceived usage of witness

1.	Never	0 – 6 months	7 – 12 months	More than 12 months

2. During lectures only	
3. During group projects	
4. During thesis project	
5. Before coming to Cranfield University / work	

7.3.2 <u>*Perceived software usability*</u>

The software usability items are listed in table 12 below

Item 1 (How easy / difficult is it to follow instructions in using the prototype?) is selected because the user should be able to easily understand how to use the prototype. Item 2 (How easy / difficult is it to navigate around the interface?) has been chosen based on the fact that navigating around a new program can sometimes be a frustrating exercise for the end user. Finally item 3 (How easy / difficult is it to use the prototype?) has been explicitly chosen to emphasize the applications ease of use.

Table 12: Perceived software usability

	Used In		
	Fakun (2000)	Zulch & Stowasser (2000)	Scholtz (2004)
1. How easy / difficult is it to follow instructions in using the prototype?		•	•
2. How easy / difficult is it to navigate around the interface?	•	•	
3. How easy / difficult is it to use the prototype?	•	•	•

7.3.3 <u>Perceived speed of use</u>

The speed of use items are listed in table 13 below

Item 1 *(How slow / fast is it to construct a model using the prototype?)* was specifically chosen to demonstrate not only the ease of use of the application but also the speed at which a model could be constructed using the RapidSim prototype. Item 2 *(How quickly can changes be made to the model?)* was chosen to demonstrate how quickly changes or modifications could be made to the modelled system when using the RapidSim interface.

Table 13: Perceived speed of use

	Used In		
	Zulch & Stowasser (2000)	Scholtz (2004)	Leavitt (2006)
1. How slow / fast is it to construct a model using the prototype?	•		•
2. How quickly can changes be made to the model?		•	•

7.3.4 <u>*Perceived key performance measures*</u>

The key performance measure items are listed in table 14 below

Item 1 *(How easy / difficult is it to measure the key performance indicators using the prototype?)* was selected based on its relevance to the case studies carried out. One of the key aspects of the case studies is based on the user's ability to effectively measure the key performance indicators of the model. Analyzing how this can be done via the prototype is an important part of the model validation process. Item 2 *(Are the tools provided to measure the performance indicators useful?)* is used as a means of measuring the effectiveness of the proposed RapidSim performance measuring tools.

Table 14: Perceived key performance measures

	Used In		
	Fakun (2000)	Zulch & Stowasser (2000)	Scholtz (2004)
1. How easy / difficult is it to measure the key performance indicators using the prototype?		•	•
2. Are the tools provided to measure the performance indicators useful?	•	•	•

7.3.5 Perceived software flexibility

The software flexibility items are listed in table 15 below

Item 1 (How easy / difficult is it to create components / modules?) is selected because the application should make component and module creation easier for the user. Item 2 (How easy / difficult is it to rearrange the physical layout of a model using the prototype?) Is chosen to highlight how simple it is for the end user to rearrange the shape or component makeup of an existing layout. Item 3 (How easy / difficult is it to alter the physical routing of parts using the prototype?) is selected because being able to make changes to the routing of parts within an existing layout should be easy and hassle free. Item 4 (How easy / difficult is it to bypass elements in a layout using the prototype?) has been chosen to highlight the flexibility of the application in terms of bypassing certain elements within a given layout. Being able to switch elements on and off should be made easy for the end user. Item 5 (How easy / difficult is it to model "breakdowns" using the prototype?) is chosen because the user will find this application critical to supporting their task. Item 6 (How easy / difficult is it to link components and run the model using the prototype?) is selected because one of the key aspects of the prototype is in its ability to facilitate easy model creation. Finally item 7 (How flexible is modelling with the prototype compared to building models manually?) is selected to confirm the overall flexibility of the prototype when compared to traditional model building techniques

Table 15: Perceived software flexibility

	Used In		
	Eden & Mens (2000)	Fitzpatrick (2004)	Brugali et al (2010)
1. How easy / difficult is it to create components / modules?	•	•	
2. How easy / difficult is it to rearrange the physical layout of a model using the prototype?	•	•	•
3. How easy / difficult is it to alter the physical routing of parts using the prototype?			•
4. How easy / difficult is it to bypass elements in a layout using the prototype?		•	•
5. How easy / difficult is it to model “breakdowns” using the prototype?	•	•	•
6. How easy / difficult is it to link components and run the model using the prototype?	•	•	
7. How flexible is modelling with the prototype compared to building models manually?	•	•	•

7.3.6 Perceived software usefulness

The software usefulness items are listed in table 16 below

Item 1 (*The prototype will help in the model building process*) is selected to establish whether or not the prototype will be a useful tool when used in the overall model building process. Item 2 (*The prototype will help reduce the overall model building time*) is selected because using the RapidSim application should result in a reduction in the time take to construct a simulation model. Item 3 (*Using the prototype allows me to create physical components easier and faster*) is chosen to establish if using the prototype results in easier component creation. Item 4 (*Linking and running the modules / components can be done easily and effectively*) is selected because using the application to perform this task should make it easier for the end user to build the model. Item 5 (*Switching and element On / Off and re-linking the model can be done easily*) is chosen to establish the flexibility and usefulness of being able to quickly, effectively and easily make changes to the constructed model. Finally item 6 *(The prototype has the potential for improving the model building process*) is selected to confirm that the prototype can have an impact on the model building process.

Table 16: Perceived software usefulness

	Used In		
	Fitzpatrick (2004)	Leavitt (2006)	Brugali et al (2010)
1. The prototype will help in the model building process	•	•	•
2. The prototype will help reduce the overall model building time	•	•	•
3. Using the prototype allows me to create physical components easier and faster			•
4. Linking and running the modules / components can be done easily and effectively	•	•	•
5. Switching and element On / Off and re-linking the model can be done easily		•	•
6. The prototype has the potential for improving the model building process	•	•	•

7.4 Experimental Setup (Case Studies)

This section of the research introduces the case studies that have been used in order to validate the work done in development of the RapidSim interface for the Witness simulation software package. The case study is structured into two distinctive parts or scenarios, with scenario 1 representing the creation of a simulation model using the manual modelling approach while scenario 2 represents the identical creation of a simulation model using the RapidSim approach. The independent variable which will be manipulated and measured in this exercise will be the use of the RapidSim interface as all aspects of both models will remain the same. It should also be noted that as a form of means testing these experiments the time taken to complete each exercise will be noted.

In scenario 1 the case study follows a model building exercise where the participants are given a structured model and asked to build said model using the conventional or manual modelling approach. In the first task the modeller is assigned a group of components as shown in table 1 (Appendix 4) and is asked to replicate the model shown in figure 1 (Appendix 4) using these elements. The participant is expected to create the connections and logic necessary for the model by inputting them manually into the model. After successful completion of the first task the participant is allowed to move onto the second task which involves rearranging the elements of the first model to now represent the layout shown in figure 2 (Appendix 4). The previous connections and logic rules which were made for the model have to be manually deleted and new routes and connections created. When the participant has completed the second task they move on to task three which looks at altering the part route and bypassing elements of the model. Participants are specifically asked to bypass the elements circled in figure 3 (Appendix 4) of the model and to create a new part route which is exempt of the bypassed elements. The fourth task associated with this case study involves the inclusion of a breakdown scenario at one of the machines. Participants are given instructions on how to create a breakdown at the machine specified and are asked to build the model shown in figure 5 (Appendix 4). After completing this exercise they are asked to run the model. The fifth and final task involves measuring the key performance measures of the model. Participants are asked to provide information regarding the average lead time of the model, the number of work in progress and to measure the machine utilization of a specified machine. If they are unable to complete this task the information is duly noted and they are then asked to proceed to scenario 2.

Scenario 2 is basically a repetition of the tasks carried out in scenario 1 but with the added use of the excel driven interface. The same parameters for the experiment are set and participants are given a structured modelling exercise to complete. The participant is given a short and concise tutorial to familiarise themselves with using the RapidSim interface lasting no longer than 5 minutes. On completion of this they are given the exercise detailed in scenario 2 of the case study and asked to build the model following the guidelines specified. On completing the exercise specified in scenario 2 the participant is then asked to give their opinions regarding their usage of RapidSim. The information collected is noted and the analysed results can be found in sections 7.5. This report will now proceed to look at the two modelling scenarios which have been presented to the participants of the study.

7.5 Experimental Results

In order to check that the manual model developed in the case study would produce the same results as the RapidSim model a comparison of both models was undrtaken by the author. The manual model was constructed following the same guidelines set aside for it’s RapidSim counterpart and the results were noted. The results obtaned from this exercise were then used to verify the results obtained by the participats in the validation exercise. It was necessary for participants to build the manual model in the first exercise to facilitate them learning through the case data. In this way modelling with RapidSim could demonstrate the software’s key features.

Table 17 Comparison of Manual and RapidSim Results

Key Performance Indicators	Manual Model		RapidSim Model	
	Exercise 4a (i)	Exercise 4a (ii)	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	685	702	679	687
Number of work in progress (WIP)?	670	697	678	695
The average machine utilisation?	32%	30.1%	34%	32%
	Exercise 4b (i)	Exercise 4b (ii)	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?	688	795	680	783
Number of work in progress (WIP)?	697	782	705	784
The average machine utilisation?	31%	24%	30%	25%

7.5.1 The Manual Model

The chart Labelled Figure 31 below shows the values obtained from the software evaluation exercise which has been carried out thus far. This exercise is based on case study 1 or scenario 1 which can be found in section 7.4 of this report. All the findings which are presented in this section are reflective of the information collected from participants upon completion of the above mentioned exercise. The chart in figure 30 displays the level of difficulty involved in constructing a manual simulation model, the level of difficulty involved in re-arranging the components within the manual model and also the level of difficulty involved in altering the given part route within the specified model. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the various levels of difficulty associated with the given exercise. A total of 12 participants took part in the prototype testing process.

Exercise 1 = “the level of difficulty involved in constructing the manual model”.

Exercise 2 = “the level of difficulty involved in re-arranging the components in the model”.

Exercise 3 = “the level of difficulty involved in altering the part route within the model”.

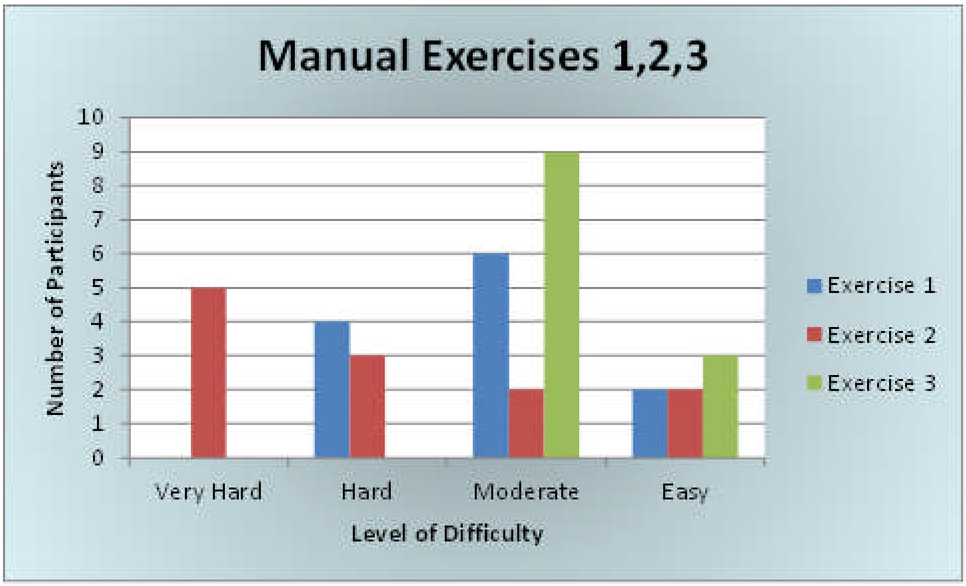


Figure 30: The manual model exercise 1, 2 and 3

From the data collected, exercise 3 proved to be easiest of all the given exercises with 75% of the sample populous finding it neither hard nor easy but moderately in between. The remaining 25% of the sample found exercise 3 to be easy. Exercise 2 was found to be more difficult than exercise 3 and exercise 1, with 41% of the populous finding it very hard to carry out this exercise. A further 25% of the populous found it hard while the remaining 34% of the populous thought the exercise to be both moderate and easy with the values shared equally between them. 33% of the populous in exercise found it hard to carry out the exercise. A further 50% found it neither hard nor easy but moderately in between with the remaining 17% finding the exercise to be relatively easy. Exercise 2 was judged as being the most difficult exercise from this grouping.

The chart displayed in figure 31 below shows the results obtained from exercise 4a and 4b of the evaluation exercise. The chart shows the level of difficulty involved in measuring the key performance indicators of the model. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the various levels of difficulty associated with the given exercise.

Exercise 4a = "the level of difficulty involved in measuring the key performance indicators of the manual model".

Exercise 4b = "the level of difficulty involved in measuring the key performance indicators of the manual model with planned breakdowns"

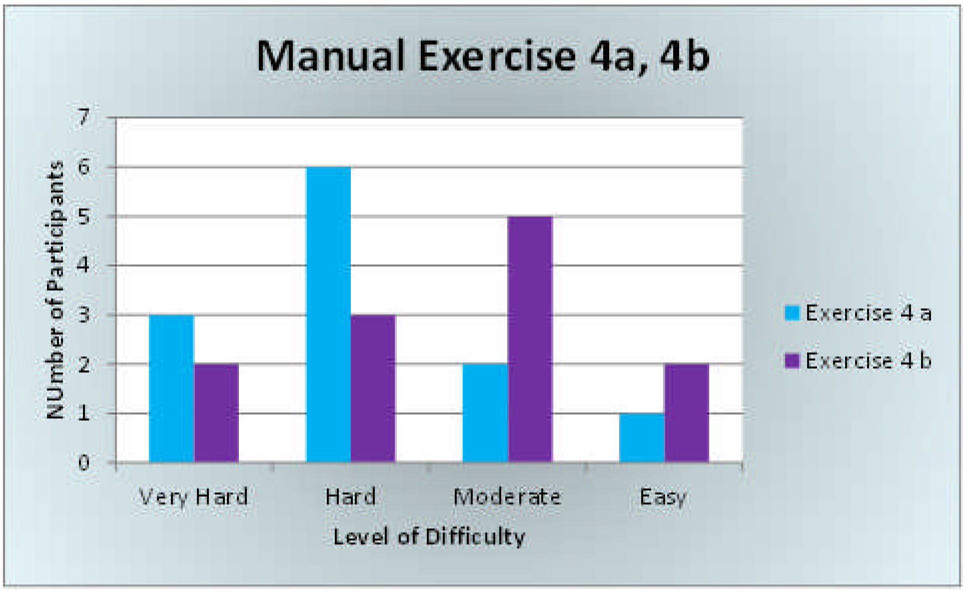


Figure 31: The manual model exercise 4a and 4b

The data collected showed that between these exercises', exercise 4b was the easier of the two. Analysis of the data showed that 25% of the sample populous found exercise 4a to be very hard whilst 50% found it to be hard. The remaining 25% of the study found exercise 4a to be moderate to the tone of 17% with the final 8% finding the exercise to be easy. In exercise 4b the data showed that 17% of the populous found the exercise to be very hard, while a further 25% found it to be hard. The remaining 58% of the sample thought that the exercise was moderate to easy with the figures reflecting their opinions. 41% of the populous thought that the exercise was neither hard nor easy but moderately in between while the remaining 17% of the study found the exercise to be easy. Compared to exercise 4a, exercise 4b was slightly easier to carry out mainly due to exercise 4b being a repetition of exercise 4a with only some minor changes added. Hence the user after familiarising himself / herself with exercise 4a was able to progress further with exercise 4b. Also it should be noted that from the populous examined only 25% were able to complete the manual model building process along with only 50%

being able to complete the key performance measures. This information can be found in figure 32 below.

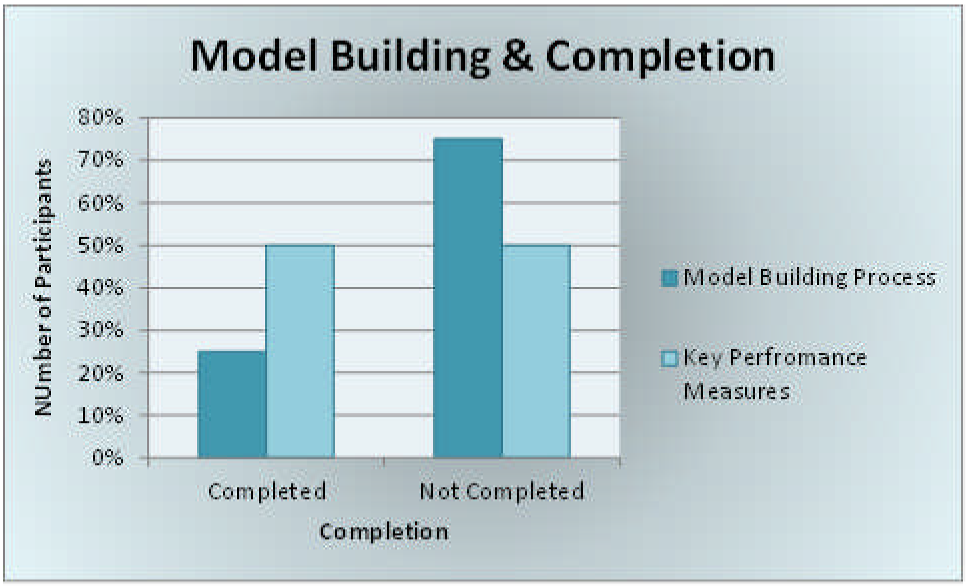


Figure 32: The model building process and key performance measure completion

As a result of the populous constructing the model as specified in the case study the overall average time for completing the manual modelling exercise was found to be 34 minutes. However it should be noted that as 75% of the study failed to complete the specified performance measure, figure 32 above, and that the average time taken does not take this factor into account. If members of the populous were left to complete these measures the average time would be considearably higher.

7.5.2 The RapidSim model

This exercise is based on case study 2 or scenario 2 which can be found in section 7.4 of this report. All the findings which are presented in this section are reflective of the information collected from participants upon completion of the above mentioned exercise. The chart shown in figure 33 details the level of difficulty involved in the construction of a simulation model using the proposed RapidSim interface. It also displays the level of difficulty involved in re-arranging the components and the level of difficulty involved in altering the given part route within the specified model. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the various levels of difficulty associated with the given exercise.

Exercise 1 = “the level of difficulty involved in constructing the RapidSim model”.

Exercise 2 = “the level of difficulty involved in re-arranging the components in the model”.

Exercise 3 = “the level of difficulty involved in altering the part route within the model”.

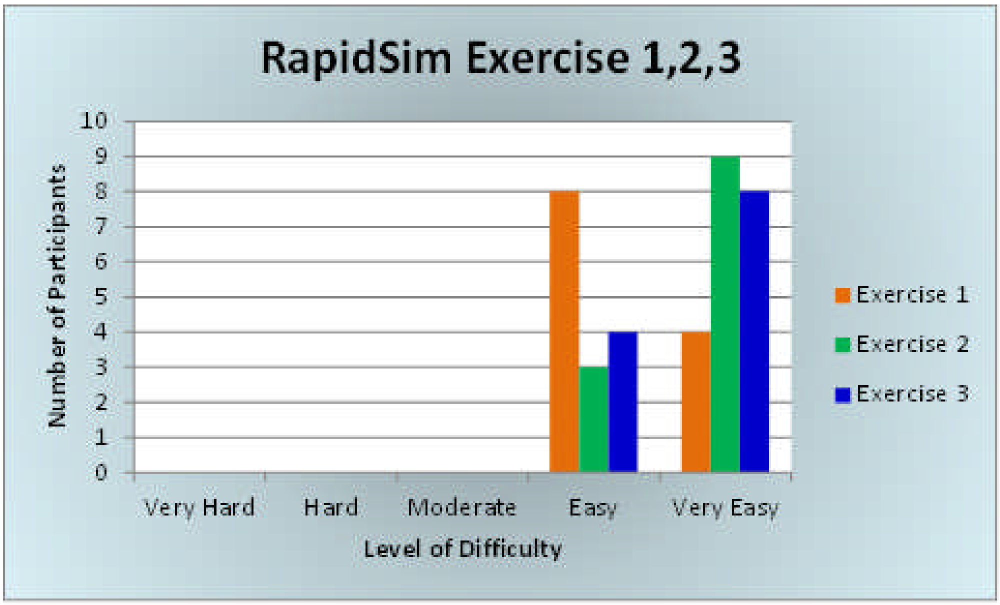


Figure 33: The RapidSim model exercise 1, 2 and 3

Using the RapidSim interface, exercise 2 proved to be easiest of the 3 given exercises with 75% of the sample populous finding the evaluation exercise very easy while the remaining 25% of the study found the exercise to be easy. Both exercise 1 and 3 were completed successfully by members of the populous, with both exercises obtaining similar results. 68% of the populous expressed the view that exercise 1 was easy while the remaining 32% found it to be very easy. In exercise 3 32% found that using RapidSim to complete this exercise was easy, whilst the remaining 68% found the exercise to be very easy. When compared to building a simulation model manually, the ease at which users could build a simulation model increased considerably when using the RapidSim method. The comparison of the two different modelling approaches to the same exercise can be seen below in figure 34.

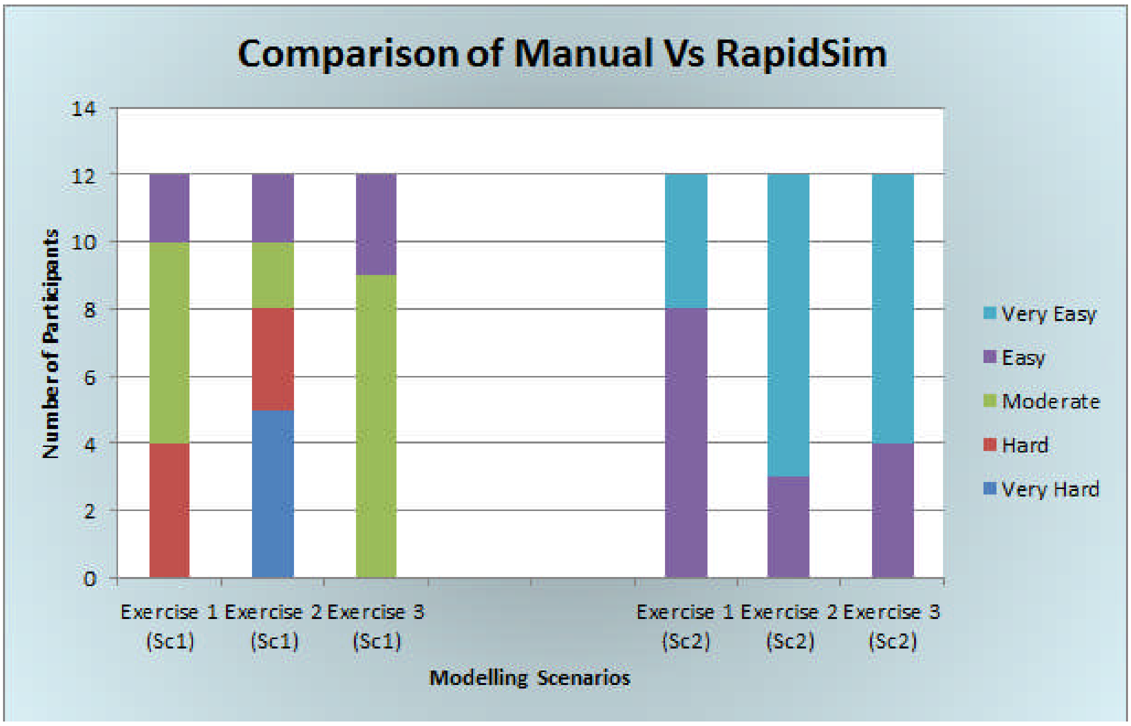


Figure 34: The comparison of manual vs Rapidsim (exercise 1)

The chart shown in figure 35 shows the level of difficulty involved in measuring the key performance indicators of the model using the RapidSim model. The Y-axis details the various levels of difficulty associated with the given exercise. The X-axis displays the number of participants who have taken part in the evaluation exercise

Exercise 4a = “the level of difficulty involved in measuring the key performance indicators of the RapidSim model”.

Exercise 4b = “the level of difficulty involved in measuring the key performance indicators of the RapidSim model with scheduled breakdowns”

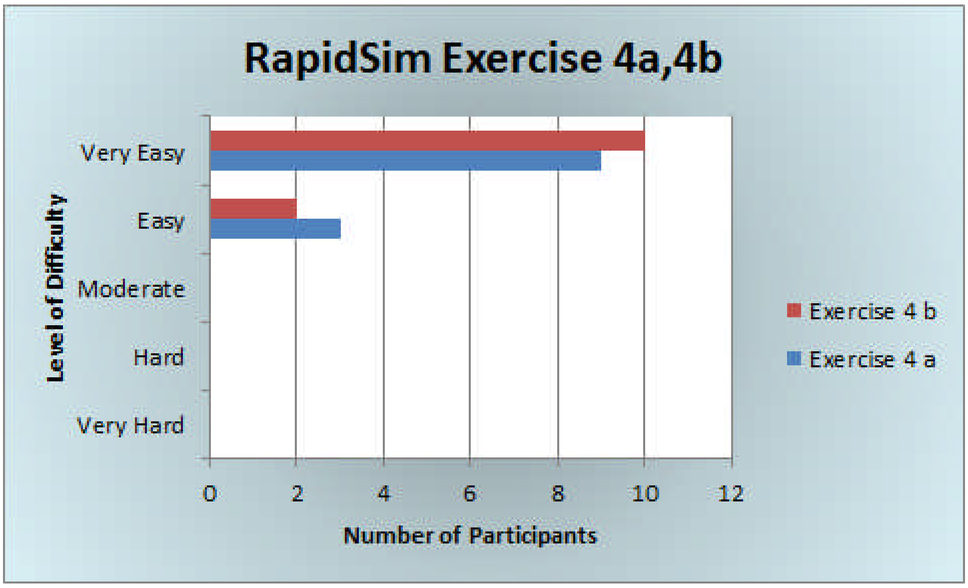


Figure 35: The RapidSim model exercise 4a and 4b

The data collected showed that between the completed exercises', exercise 4b was the easier of the two. Analysis of the data showed that 25% of the sample populous found exercise 4a to be easy whilst the remaining 75% found it to be very easy. The data from exercise 4b found that 17% of the populous found the evaluation exercise to be easy while 83% found it to very easy. Compared to exercise 4a, exercise 4b was slightly easier to carry out mainly due to exercise 4b being a repetition of exercise 4a with only some minor changes added.

Also it should be noted that from the populous examined 100% were able to complete both the manual model building process and the key performance measures. Comparison of the manual model vs. the RapidSim model showed a substantial gain in the user's ability to complete both the model and the key performance measures. This information can be found in figure 36 below.

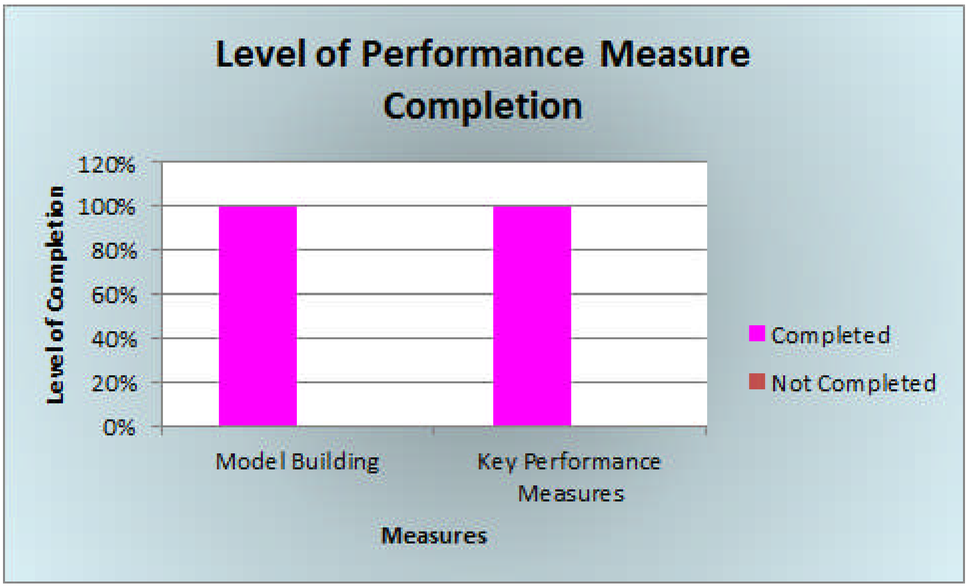


Figure 36: The RapidSim model building process and key performance measure completion

User Feedback:

The populous engaged in the validation process had varying levels of experience in using the Witness simulation software package with 25% of those sampled indicating that they had no previous experience in using Witness. 25% of the sample had between 0 – 6 and 7 – 12 months experience respectively whilst the remaining 25% had more than 12 months experience. In terms of witness usage, 50% of the populous indicated that they used Witness during university lectures. A further 25% of users indicated they used witness for their thesis projects, with the remaining 25% of the populous having never used witness before the validation exercise. The charts displayed in figure 37 and 38 details the information discussed above.

Figure 37: The users level of witness experience

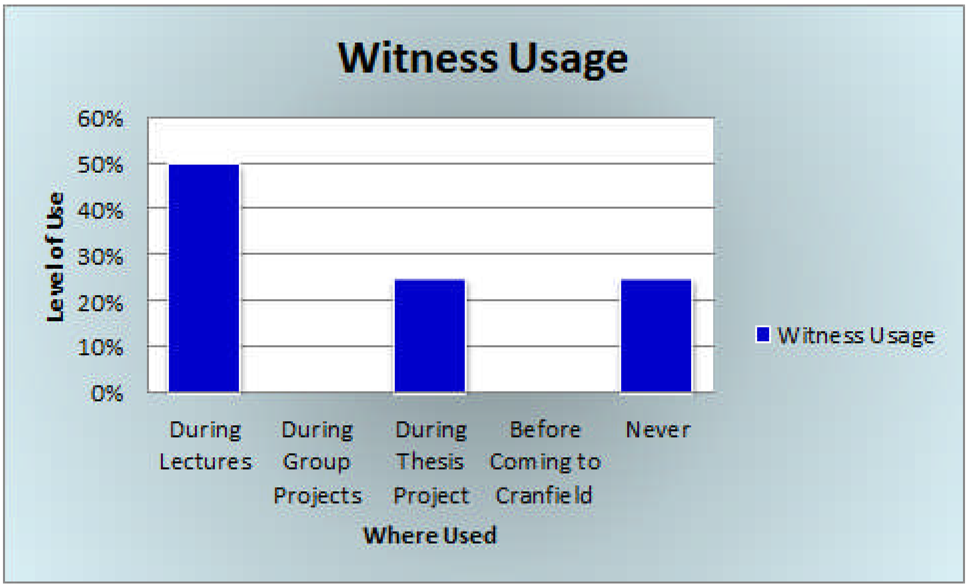


Figure 38: The users level of witness usage

Figure 39 displays the level of difficulty the user faced when using the software interface. It also looks at the overall ease of use of the prototype as well as the level of difficulty involved in navigating around the interface. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the various levels of difficulty associated with the given exercise.

When following the guidelines on using the interface 50% of users found the instructions easy to use while a further 25% indicated that the guidelines provided were very easy to understand. The remaining 25% of the populous indicated that the written guidelines were neither hard nor easy but moderately in between. Similarly 25 % of the users found navigating around the interface to be moderate and very easy respectively. The remaining 50 % of users indicated that navigating through the interface was easy. The category which scored the highest in this grouping was the overall use of the prototype with 75 % of the populous finding the prototype very easy to use, while the remaining 25% found it easy.

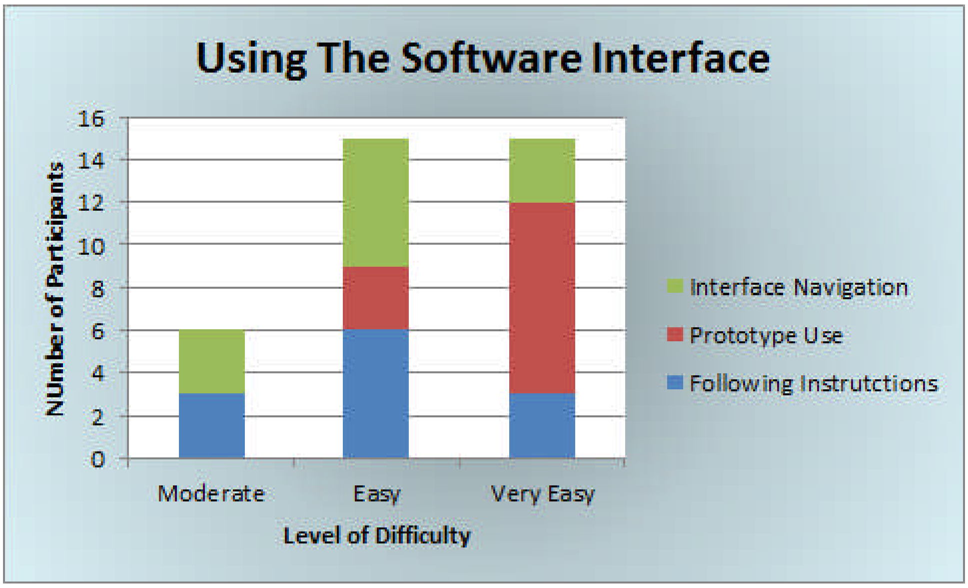


Figure 39: Using the software interface

The speed of the RapidSim prototype was evaluated and the emerging trend of the RapidSim exercises being easy to carry out was collaborated by the results obtained. From the sample taken 75% of the populous found the speed of building the model using the RapidSim prototype to be fast while the remaining 25% found it to be very fast when compared to the manual modelling method. Also members of the populous were in unanimous agreement (83%) that it was fast to make changes to an existing model when using the RapidSim prototype. This information is detailed in figure 40 below.

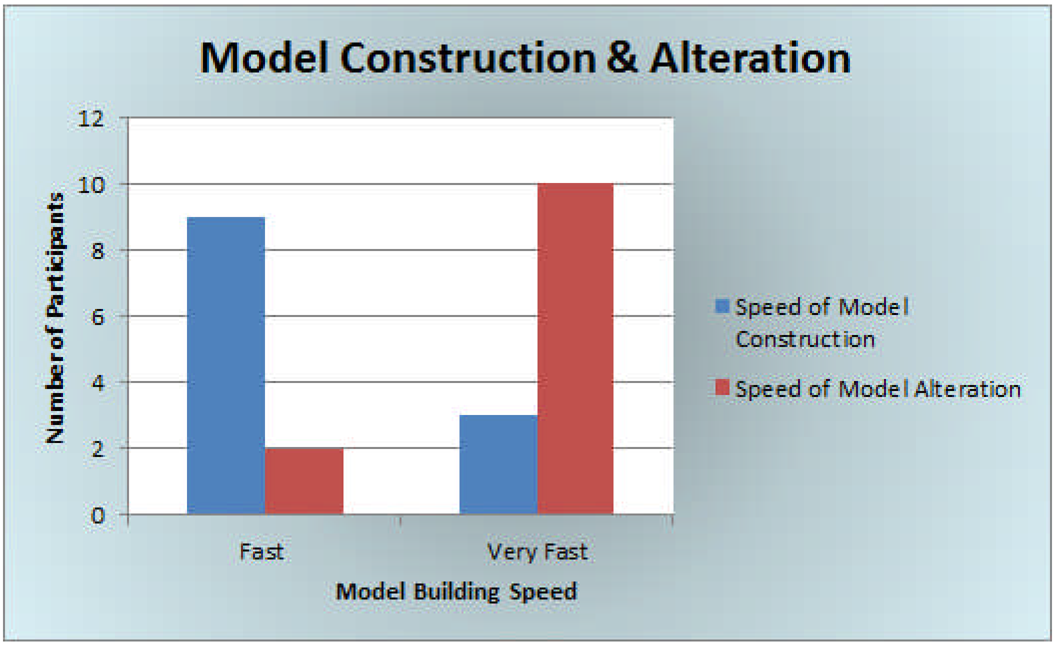


Figure 40: Speed of model construction and alteration

As mentioned above, not all members of the populous were able to carry out the key performance measures when building the manual model. In fact 50% were unable to carry out this exercise when using the manual modelling technique. A further 75% of the populous were unable to complete the manual modelling exercise altogether. However there was a significant increase in both these areas as members of the populous were able to fully complete (100%) both of these exercises when using the RapidSim method. Figure 41 displays the level of difficulty associated with measuring the key performance measures and also the usefulness of these measures. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the various levels of difficulty associated with the given exercise.

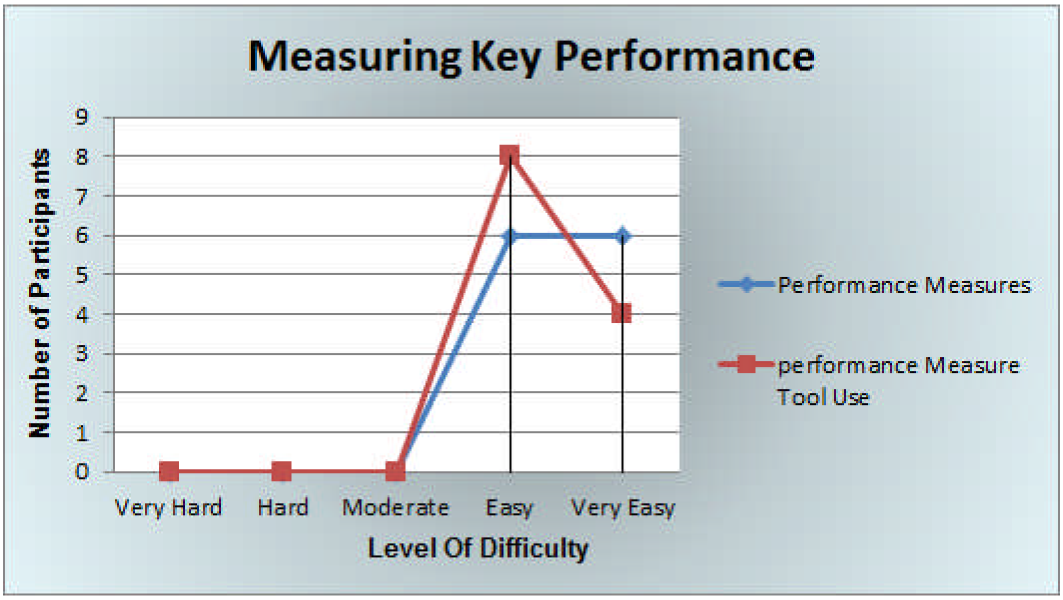


Figure 41: Measuring the key performance measures

The system flexibility part of the exercise generated some interesting results. Firstly 75% and 25% of the members sampled found that it was easy and very easy respectively, to create components / modules using the RapidSim prototype, Add to that, 50% of the populous found that it was easy to rearrange the physical layout of the model with the remaining 50% finding it very easy. There was a rapid decrease in the level of difficulty when having to alter the physical routings of the parts using the prototype with 66% of the populous finding this to be easy, and 17% finding it to be moderate and very easy respectively.. A further 25% found that it was easy to bypass elements within the model, whilst the remaining 75% of the populous found this task to be very easy. The introduction of breakdowns into the system was also measured and the results obtained showed that 58% and 17% of the sample thought that it was easy and very easy respectively with the remaining 25% finding it moderate to introduce and measure breakdowns using the RapidSim method. 100% of the populous unanimously agreed that it was easy to link the components and run the model using the prototype. Finally a further 50% of the populous indicated that modelling with the prototype was flexible while the remaining 68% found it to be very flexible when compared to building models manually.

The chart shown in figure 42, displays the level of difficulty associated with measuring the key system flexibilities. The Y-axis details the number of participants who have taken part in the evaluation exercise while the X-axis details the prototype flexibility.

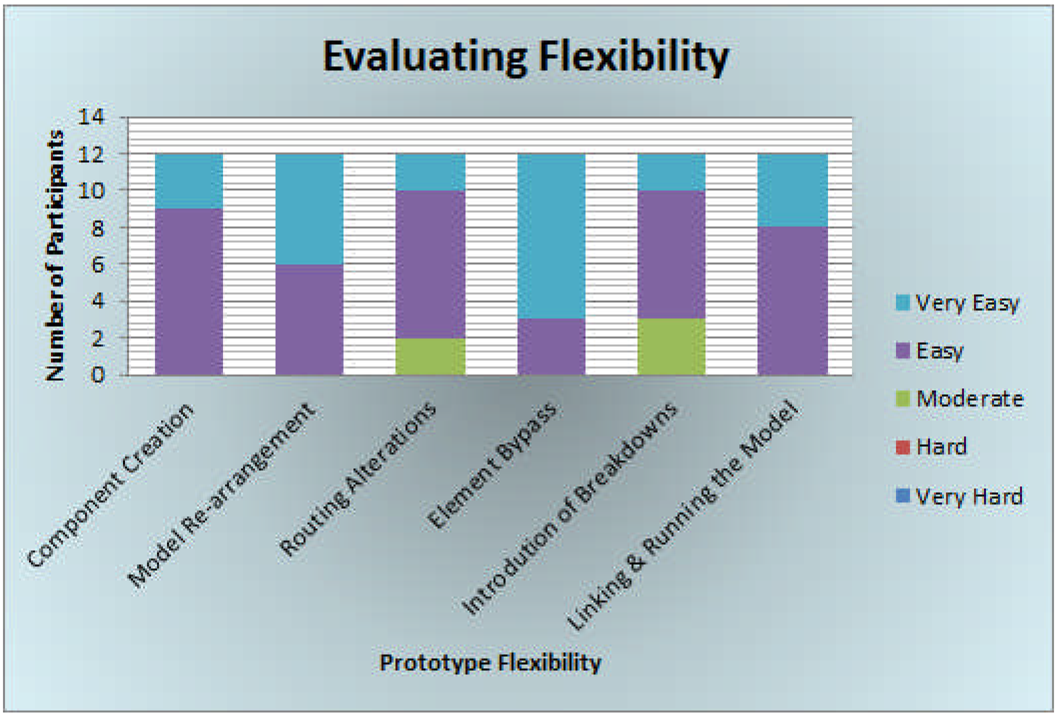


Figure 42: The level of difficulty associated with measuring the key system flexibilities

Finally the overall usefullness of the protype was measured with 100% of the sammple strongly agreeing that the protype will reduce the overall model building time. Also 25% and 75% of the sample group agreed and strongly agreed respectively, that the RapidSim Prortype would help in the overall model building process. Members of the populous were also torn down the middle between agreening and strongly agreeing that the prototype allowed them to create physical model components easier and faster. Furthermore 68% of the sample agreed that linking the modules and components can be done easily and effectively whilst 17% each moderately and strongly agreed respectively. 83% of the sample also agreed that switching elemnts on and off and re-linking the model can be done easily. However the most significant result was obtained when members of the populous agreed and strongly agreed to the effect of 17% and 83%

respectively that the RapidSim prototype has the potential for improving the model building process.

The chart shown in figure 43 displays the level of agreement amongst the sample populous when evaluating the overall prototype usefulness. The Y-axis details the prototype usefulness while the X-axis details the number of participants.

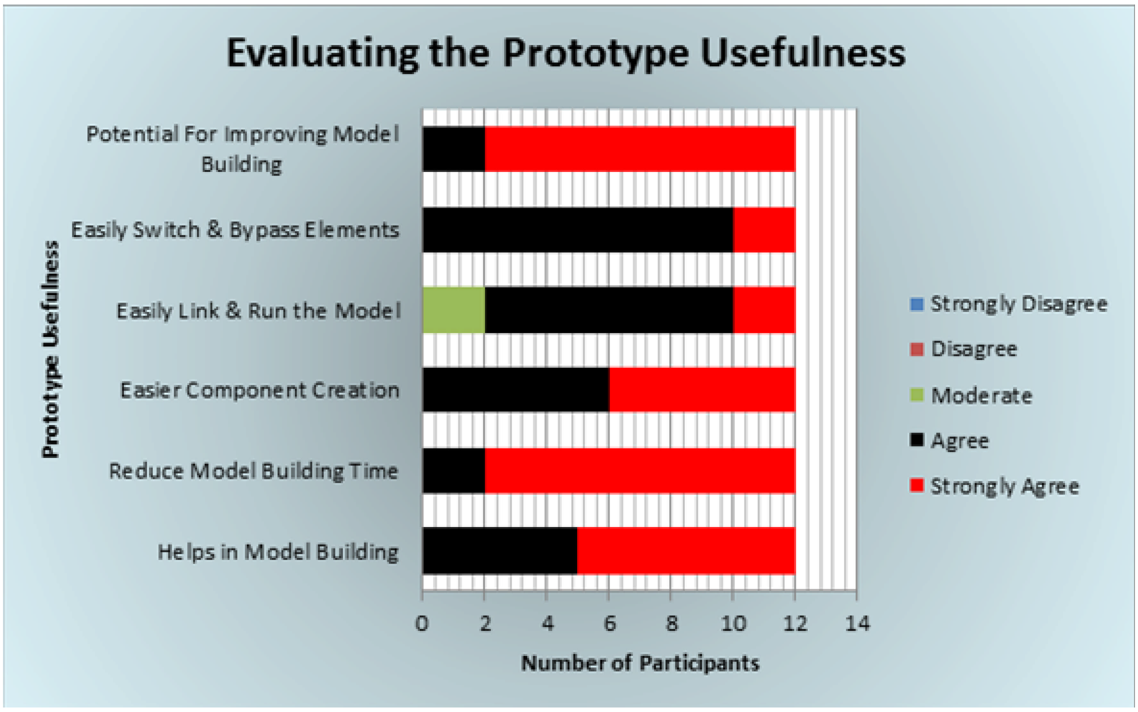


Figure 43: The level of agreement when evaluating the overall prototype usefulness

The information gathered from the evaluation exercises points towards a considerable increase in the speed in which simulation models can be built when using the RapidSim interface. The data also suggests that the model building process has become a lot easier when using RapidSim as opposed to the manual modelling approach. The overall average time for completing the RapidSim modelling exercise was found to be 12 minutes whilst the average modeling time for the manual model was found to be 34 minutes.. When compared to the Manual modelling approach the RapidSim method has demonstrated that this approach makes simulation model building 2.8 (280%) times faster, or takes 65% less time than the traditional manual approach. Figure 44 shows a comparison of the average time taken when uisng both the conventional and the RapidSim approach.

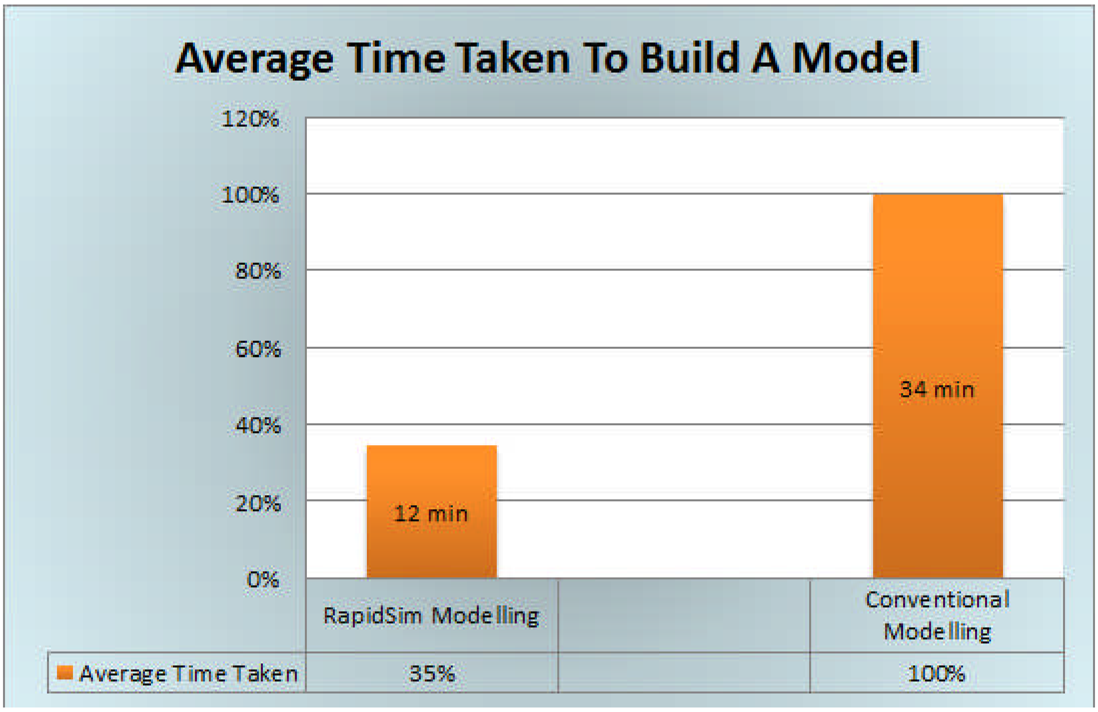


Figure 44: Comparison of the average time taken

7.6 Conventional Modelling Vs. the RapidSim Approach

Having previously looked at the basic concepts as well as the requirements for the conceptual design of a simulation model it now necessary to take a look at how a conventional or traditional model is developed, and how this differs to the proposed RapidSim approach. As in both cases the simulation model begins its development from a conceptual idea or model. However it should be noted that this is the only significant similarity which exists between both approaches. In the traditional approach the model is assembled one component at a time and then the necessary connections (inputs and outputs) are then added. The logic needed for the components to work and be interconnected is then added along with the part routing and shipping elements in order to complete the model. The following example best illustrates the conventional approach to model building. Lets consider a simple production system which is made up of a machine, a worker, a buffer and a conveyor.

Using the traditional approach to modelling the model will have to be built by firstly selecting a machine, then an element of labour then a buffer and finally selecting a suitable conveyor and putting it on the screen. Secondly the modeller will have to create all the necessary links or path routes by clicking on each element and then detailing their input and out rules. Thirdly the modeller will have to detail the elements in regard to the machines cycle time, the buffer size and the conveyor length. Finally the modeller will have to give the last element a shipping command to complete the model. Also it should be noted that any changes to the system for e.g. the addition or subtraction or a new component results in the modeller having to add or delete the part routes as well as the command rules for the element before the new model can be used. The steps mentioned above can become very tedious and more importantly very time consuming when dealing with a large, complex model. Having taken a brief look at the conventional approach to simulation modelling it is only fitting that we explore the disadvantages which are associated with this type of modelling. The disadvantages to this approach are listed as follows;

Cost: The cost of using a simulation based software package is not cheap and it is one of the most important factors which are influenced by the company's available resources. The software license cost is a significant factor prohibiting the uptake of modelling and simulation amongst users.

Time Consumption: The development of any simulation model, especially one which is built from scratch can be a very time consuming and labour intensive exercise "as models must now be custom developed for each simulation software package" (McLean and Leong, 2001). Law and Kelton, (2000) found that "the lack of precedence of simulation and modelling involving a new manufacturing system or technology hinders the process, since previously developed and tried out models could support the present process as proven reference models".

Data Usage: Most of the simulation models which are developed today rely on a significant amount of data in order to construct the model. In some instances this data many not be readily available to the modeller or modelling team. However, when it is present it requires a large amount of analysis to be transformed into a form that is suitable for use in a simulation model.

Expertise: One of the most important factors to consider in any simulation modelling exercise is the human factor. "The development and analysis of simulation models require specific skills" (Rohrer and Banks, 1998). The simulation model developers require certain skills, in conceptual modelling, validation and statistics as well as being versed in the use of the software package needed to develop the model. Modellers must also possess the skill of dealing with people as this helps in the data collection process. This level of expertise does not come cheap and as such the factor of cost once again must be considered.

Overconfidence. An individual's perception that anything which has been generated via a computer model tends to be right is a dangerous approach to model development. The use of animated displays and 3D modelling further exacerbate this problem by giving the model an appearance of reality. Results obtained from simulation studies must always give some consideration to validity of the underlying model and the assumptions and simplifications that have been made. Having taken a brief look at the conventional approach to simulation modelling the focus will now shift towards the proposed RapidSim model. In the context of this research the focus will be on the use of cladistics as a method for classifying the templates. Cladistics can be simply defined as the hierarchical classification of species based on their evolutionary ancestry and it can be distinguished from other taxonomic classification systems as it focuses its attention on evolution rather than on the similarity between species and it places heavy emphasis on objective, quantitative analysis. The novelty of this research will further the field of rapid simulation development and upon its completion will provide advancements to our knowledge base by:

1) Using cladistics and evolutionary analysis as the basis for a classification of manufacturing systems layout types.

2) Investigation into a new and novel approach to the rapid generation of simulation model templates based on the manufacturing layouts identified.

3) Changing the approach to simulation model development from one of ‘model building’ towards one of ‘model assembling’. The development of a ready to use component library which facilitates the easy retrieval of model elements as well as the automatic generation of the completed model will be used to speed up the model building process.

The most important concept of the RapidSim modelling approach is the use of pre-built ready to use templates which can be used on their own or in combination with other templates to quickly design, assemble and run a simulation model. Referring to the example used above to discuss the conventional modelling approach i.e. the use of a machine. labour, a buffer and a conveyor one can see how these two approaches differentiate from each other. In the RapidSim approach the components are all combined together to form a single module which contains all the part routing, the inputs and outputs and the necessary logic for making the model work. One of the most important aspects to this approach is repeatability. Modules can be used and reused within any simulation model thereby eliminating the need for continuous design or redesign. As modules are made up of various combinations of simulation components (machine, buffer, conveyor etc.) building a model is as easy as selecting the modules which represent the components used in the system and simply assembling these modules in a template to form the completed model.. Figure 46 below illustrates a module which has all the required components, rules and logic built into in.

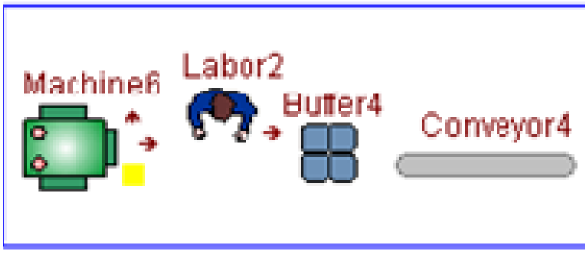


Figure 45: A simple module

Using the RapidSim approach to modelling has certain advantages to the conventional modelling approach and these are as follows;

Reduced Cost: As the RapidSim interface is built through Microsoft Excel which is readily available in most if not all companies today the cost to the user becomes lower. End users simply need a working licence of the simulation software on a shared server in order to develop models when needed.

Reduction in Time: The development of any simulation model, especially one which is built from scratch can be a very time consuming and labour intensive exercise. Using RapidSim the time taken to develop a model is reduced as models do not need to be created from scratch but simply assembled from the pre-defined components which are set aside in the modelling library.

Reduced Expertise: One of the most important factors to consider in any simulation modelling exercise is the human factor. The level of expertise when developing a simulation model does not come cheap but with RapidSim this cost can be significantly reduced. Modellers need not be experts when using the RapidSim approach as it is designed for both novice and expert users alike.

Increase in the Ease of Use: By using a purpose built interface designed in Microsoft excel to drive the simulation engine, most of the work is now done on excel rather than on Witness. Novice users who are familiar with Microsoft Excel are now able to build simulation models.

Increase in Speed: Using the RapidSim approach increases the speed at which simulation models can now be created as models are now assembled from a template based model library. Model assembly makes this approach 65% faster than the conventional method.

Increase in Flexibility: The RapidSim interface allows for the easy addition or subtraction of components from within the simulation model. Models can be designed and redesigned easier when compared to the conventional modelling approach.

Ease of Use of Performance Measures: Using the conventional approach to modelling, performance measures which capture statistics such as the average lead time, the number of work in progress and the average machine utilisation are not easy to document, and for users who are unfamiliar with Witness it is near on impossible. However this is not the case with the RapidSim approach. Statistics regarding the average lead time, the number of work in progress and the average machine utilisation is captured for the use in the form of graphs and pie charts in the modelling window. The user simply needs to read these values in order to obtain a statistical report.

The points mentioned above clearly identify the advantages and potential benefits in using the RapidSim modelling approach as opposed to the conventional methods used in constructing simulation models.

7.7 Discussion of Results

The results obtained from the experiments conducted as part of the validation exercise shows that the RapidSim approach to modelling has some significant advantages when compared to the conventional modelling approach. The results are based on a total of twelve participants who took part in the validation exercise. The use of the Excel driven interface showed that it was easier to create and run a model using RapidSim. In all aspects of the case study test the RapidSim interface was found to perform better than the conventional modelling techniques employed. Comparison of the first exercise in scenario 1 and 2 (exercise 1,2,3) where the level of difficulty involved in constructing a model, re-arranging the components of the model and altering the part route within the model was measured and it saw a shift in the level of difficulty associated with this task.

In scenario 1, users found the degree of difficulty associated with the manual model building task to range from being very hard to moderate whilst in the RapidSim approach this shifted from being very hard to being easy and very easy. The second task conducted (exercise 4a, 4b) produced similar results whereby participants were asked to measure the key performance indicators of the manual model. This resulted in 50% of participants not being able to complete the performance measuring part of the exercise as they found it to be very hard to moderate with only 1 user finding it easy. A further 75% were unable to complete the manual model building exercise as a whole.

This however was not the case with the RapidSim model as users were able to fully (100%) complete both the model building exercise as well as the key performance measures. Furthermore participants indicated that they found this part of the exercise to be very easy when compared to the manual approach used before. The results collected also highlighted the fact that users, who had no previous knowledge using the witness simulation software or any simulation package for that matter, were able to successfully complete both the model building exercise as well as the key performance tasks. Another factor which was highlighted during the modelling exercise was the user's perception of using the interface. More than 80% of the sample found that using the prototype was very easy and more than 50% indicated that navigating around the interface and following the guidelines provided were easy.

The flexibility of using the RapidSim model was clearly visible from the data analysed as participants found the tasks of component creation, model re-arrangement, routing alterations, element bypass, introduction of breakdowns, linking and running the completed model to be easy and very easy when compared to the conventional modelling approach. Also the feedback collected regarding the prototype usefulness was very encouraging. Participants agreed that the RapidSim prototype helped in easier component creation, in building linking and running the simulation model and in easily switching & bypass elements of the model. They also strongly agreed that the RapidSim model helped in reducing the model building time, that it helped improve the model building process and that it has the potential for improving the way in which simulation models are built and run.

The most important fact gathered from all the tests carried out to validate the model was the time taken to build and run the model. Analysis of the data showed that using the RapidSim approach led to a reduction of 65% in the time taken to build and run a simulation model. This just goes to show that the RapidSim interface can have a positive impact in the simulation and modelling community.

7.8 Overall Discussion of Validation

All activities relating to the validation process were properly documented and although this may seem a daunting task, following this method in a simple and systematic way allowed for a proper validation procedure to constructed and completed.

There are two main tasks which have been associated with the validation process, they being;

Preliminary work: This deals with the specification of the requirements as set out in stage 1- 3 of the proposed validation methodology. It also focuses on the management of the design and software development process as well as the design and development of the validation test plan and the installation requirements and procedures. In this instance the test plan dealt with the case studies developed in section 7.3 of this report.

Peer review and test: Testing follows the process of evaluating a system or system components either manually or through automation to verify that it / they satisfies all necessary requirements and it can also be used as a means of identifying differences between expected and actual results. It was necessary to review all documents regarding the validation process and to conduct and approve the planned tests and installation procedures. Following the guidelines of the validation process the software was designed to handle critical events which may occur during its use. Each step in the design and validation process was carried out after consulting the necessary people involved in the project (supervisors and peers). This allowed a step by step design process which culminated in the design of a completed user interface which needed little or no modification to the final design. The test specifications were all approved prior to testing and the persons involved in the validation process were all authorized to do so. It should be noted that the software acceptance test was completed by the system user/owner rather than by the development team or the participants.

The validation approach used for this part of the research was useful in determining the overall design and implementation of the user interface. It allowed transparent guidelines at each design stage, thereby reducing the unwanted need for over designed features and complex and illogical coding. It helped in developing an experimental testing procedure that was used to fully test the workings of the interface as well as determine how problems and changes to the system could be avoided or dealt with.

7.9 Summary

The work presented in this chapter detailed the work carried out in validating the design of the template based library and the external user interface. The interface validation was based on experimental testing and work in this chapter also highlighted the case studies which were used to test the interface and the analysed results which were obtained from those exercises. The overall method of validation as well as the overall discussion of the validation procedure was also discussed.

Tests carried out on the RapidSim interface yielded some of the following key finding;

- The interface designed has been proven easier to use than conventional modelling techniques.
- Model building and component creation is quick and easy to construct.
- Using RapidSim is a lot more flexible than conventional modelling.
- There are a lot of benefits to be obtained for the use of the RapidSim approach in regard to measuring key performance indicators of a model.
- Compared to the conventional modelling approach the RapidSim approach to simulation model building has been proven to be 65% faster.

Chapter 8

Discussion and Conclusion

8 DISCUSSION AND CONCLUSION

The work presented in this chapter will focus on summarizing the key findings and observations which have been presented in this thesis. The contributions to knowledge as well as the limitations of the research will also be highlighted in this section. The conclusions drawn from the research will also be discussed.

8.1 Discussion

This section of the thesis will discuss the main research findings and observations as well as providing a summary of the key chapters that make up this thesis.

8.1.1 Key Observations from the Research

The use of simulation has been adopted within a large number of businesses and industries in order to deal with a wide variety of problems and applications. Simulation is quickly becoming the tool of decision makers and planners when dealing with the design or redesign of new or existing manufacturing layouts. This thesis presents a new and evolutionary approach to the construction of simulation models through the use of modular template based modelling libraries. Unlike many of the existing approaches to repetitive model development the RapidSim approach utilizes a generic based module approach which allows for the construction of modules that work in any given layout type. This approach is far more flexible than the conventional modelling approach used and it is also more intuitive. The model is built via the use of an Excel driven interface, allowing for the construction of far more complex models in a shorter time frame.

The RapidSim approach utilizes the concept of cladistics to aid in the development of template based modules which allow for a more efficient and faster method of model construction. The field of simulation and template based modelling is examined in detail taking into account the views of previous work done in this rapidly maturing area. The key findings in the development of the rapid model generator and template based library are presented here as well as the overall approach to the practice of simulation model development.

Literature Review

The research undertaken in this thesis aims at bringing about a solution to the low uptake of simulation and modelling within the manufacturing sector. A review of literature relevant to this field of study has been carried out in order to gain a better understanding of how researchers have dealt with this problem in the past. This research has examined the areas of simulation modelling and construction, template based modelling and cladistics. From the literature reviewed the model building process has been described as one of the key steps in any simulation study, which requires simulation modellers to fully understand the problems, envisage and construct the model elements and identify the relationships that logically link those elements together (Guru & Savory, 2004). The review also highlighted the fact that model building and testing can take up almost 40% of the total simulation study.

Tjahjono and Baines (2004) reported that there has been a movetowards the use of simulation by people who are not necessarily experts in simulation, such as manufacturing engineers, production planners etc. For that reason, approaches have been taken to make simulation tools easier to use, which in turn will speed up model building. One such approach to the development of rapid simulation modelling has been through the use of model templates. A template, in the context of simulation and modelling, is referred to as a collection of user-defined, ready-to-use and re-usable building blocks that are created by programming their functionality, interface and performance indicators in an appropriate simulation environment. Over the last few years attempts have been made to harness the potential of modular simulation development in the model building process so as to increase the speed at which simulation models can be developed. Information presented in the review also found that the majority of template based approaches which have been developed thus far have all been developed for a specific application or industry.

The main concept behind the template based modelling approach can be seen as the development of modular simulation building blocks. The area of modular simulation building has been around for some time and work carried out in this field reflects the various proposed methodologies which aim to formalise the modular and hierarchical construction of simulation models. These methodologies also demonstrate that modular construction is an on-going theme. The use of a neutral template based modelling libraries can help in facilitating the reuse of simulation models from different simulation environments and different simulation scenarios.

Despite recent developments in the field of template based modelling the use of modules as the building blocks of repeatable and reusable simulation models still remains a largely unexplored area. This is mainly due to the complexities involved in designing a template or module which can be used across varying disciplines and under varying scenarios whilst maintaining the templates neutrality. The concept of model reuse has gained a lot of momentum over the last few years, leading researchers to suggest that component based simulation is advantageous to the model building process as it reduces the time taken for model construction especially if pre-engineered components are at the modellers disposal. The fact that most of the templates which have been developed thus far are domain specific makes the concept of model reuse a lot more difficult. However an evolutionary approach called RapidSim presents a more flexible and dynamic way of creating simulation based models which can be used in any given modelling scenario. It is the use of pre-defined repeatable and reusable modules which offers the most promise to the field of simulation model development.

It was evident from the literature review that a significant amount of work has gone into promoting the use of templates in simulation model building. However it was also made clear that the generality and the robustness of the application of such a method remains the gap that requires further investigation and validation, particularly within various manufacturing sectors. A thorough review of literature consequently revealed the reasons for this gap.

From the literature it was identified that the solutions described are often customised to a very specific domain and were developed to fit within the framework or programming paradigm of a particular commercial simulation tool. The implication of using these domain specific templates is that additional work is often required to customise the template, which often requires even more expertise in using a particular simulation tool.

The review found that the models generated using templates are generally limited to systems with regular patterns, for example, machining lines in a car engine factory. The machining lines typically consist of a set of machines, followed by conveyors and buffers. A conveyor carries parts to be machined and a buffer stores the machined parts as work in progress (WIP). The 'conveyor-machine-buffer' configuration is in fact a building block that, because of its regular pattern, can be duplicated and linked together to construct a complete machining line.

Manufacturing systems evolve over time. For example, Ford was once known as a craft manufacturer which then evolved further into a mass manufacturer and then into a lean manufacturer due to market competition. This means the problems being addressed by using simulation can also evolve depending on the systems being modelled. Finally, although templates can be developed based on similarity of the system's layout, the type of problems being addressed by manufacturers and the type of decision making can be completely different.

This research has addressed the area of an evolutionary approach to the rapid design of simulation models through the use of cladistics and evolutionary analysis. This approach has focused on the modular based design of simulation modules and how these modules can be linked to form a template based modelling library. The problem of domain specific and generic module creation has also been addressed by this research along with the creation of an external interface which is used to drive the simulation modelling engine. This is the first instance in which cladistics has been used to develop a neutral template based modelling library and as such the proposed RapidSim approach is novel.

The Model Pattern of Manufacturing Systems

The work presented in this section of the thesis aided in establishing a thorough understanding of the diversity and types of manufacturing system layouts that exist. The collection of information on the different types of manufacturing system models, based on the nature of their manufacturing processes, their typical layouts, material flows, routing logic etc. was used to categorize this information into a classification system. The literature review identified various manufacturing systems which all use simulation at one time or the other as a decision making tool. These systems were then compiled and classified according to the type of production they employ and a total of eleven (11) different manufacturing systems which are thought to be the most commonly used layout types in the manufacturing sector were identified.

The literature review found that simulation models have become more prevalent in both the business and industrial sectors thus making the use of simulation not as alien a concept as one would have thought. In today's fast paced and highly industrialised society the use of simulation, simulation based technologies and modelling are becoming an important and indispensable factor in the way manufacturing companies are able to remain competitive in the global market place. Greater technological and industrial advances in both the manufacturing and business sectors respectively have led to a work culture which facilitates the need for and the adoption of, simplified work techniques which are both user friendly and cost effective.

The approach taken in this section also focused on the overall simulation model development process. Information presented here highlighted the modelling and simulation process as well as the need for simulation within the workplace. The requirements for proposed conceptual model was also detailed and discussed. This section also detailed the comparison between the conventional modelling approaches used and the proposed RapidSim method. Both methods were examined based of factors such as modelling cost, time consumption, data usage and expertise but to name a few, and the benefits of the new approach was noted. The most important concept of the RapidSim modelling approach i.e. the use of pre-built ready to use templates which can be used on their own or in combination with other templates to quickly design, assemble and run a simulation model was also discussed.

After research and analysis into the different manufacturing systems types identified in the review, the commonalities and differences which some of these systems may possess were identified and the data displayed in the form of a classification system. Review of the literature showed that although the use of machines, buffers, conveyors, workers and the quantity or volume of production were present in most of the systems identified, these factors alone were no enough to formulate a classification. As the classification was based on the layout types identified from the literature review it was only fitting that the characteristics which make up these various layouts form the differentiating basis for the classification. The total number of characteristics identified came to 14 and included characteristics such as dedicated cells, product flexibility, sequential part movement and automatic machine changeovers but to name a few. The classification depicted the different types of physical layouts identified from the literature research process

Using Cladistics to Develop a Model Library

The work detailed in this chapter focused on how cladistics has evolved over time and how this concept has been put to use in the manufacturing industry. The main focus has been on the cladogram building process, culminating in the design and analysis of the cladogram of manufacturing system types and simulation system components. The information obtained from the development of the cladogram was used to design the template based simulation modules.

From the literature it was established that a cladistical classification of manufacturing organizations could provide a system for conducting, documenting and coordinating comparative studies of manufacturing organizations. Such a system could provide the consensus for formally approving, validating and typifying the emergence of new manufacturing forms. Cladograms would represent the contours of change for a manufacturing industry, thus providing knowledge and observations on the patterns of the distributed characteristics exhibited by manufacturing organizations over their evolutionary development.

It was also established from the literature that if a classification is linked to this change process, it is postulated that groups of manufacturing systems can be formed based on similar technological and behavioural attributes, and that there will exist an “ideal model” or solution for the group. This group reference model will then help reduce the time and costs associated with developing solutions for individual companies within that group. The investigative process of developing a cladogram also helps in enhancing the investigators' knowledge and understanding of manufacturing systems thereby enabling predictions about system behaviour. As product changes have often triggered a change or a series of changes in its manufacturing system, it is envisioned that a newly installed manufacturing system or machines, would encourage product changes to utilize most of the extended system capabilities.

The author found that by applying the process of cladistical analysis to the data collected the information is rearranged, and then re-inserted into the evolution path, thereby forming a regular pattern. Use of a cladogram helped in establishing the overall evolutionary picture, as layout variations which occur via multidirectional evolutionary branches are streamlined to show how innovation and improvements affect the evolutionary path and the manufacturing system as a whole.

The cladogram building process established two cladograms which were fundamental to the development of the neutral template based library. The first cladogram depicted the evolution of manufacturing layout types whilst the second depicted the evolution of simulation component types. The information contained in both these cladograms was combined to create the modules needed for template generation. In developing the cladogram it was found that the logic rules which were used for modelling single elements also evolved as the component type evolved, with the rules becoming more complex as the complexity and functionality of the combined components increased. From the data analysed it was found that repetitive patterns in regard to the physical makeup of these systems were becoming more frequent and in use throughout a number of different manufacturing systems.

After reviewing the current literature on the use of cladistics it was found that not only has the use of cladistics become more widespread in the field of classification but its use is also becoming more widely adopted in the manufacturing sector. The Construction of a classification using evolutionary relationships is considered to be beneficial, as the classification would be unique and unambiguous thereby showing only the true relationships which exist between the various layout and component types. Since cladistics can be used to identify the current layout variants / families and groups, it can also provide guidance for deciding upon the relevance of a new layout within an existing group / family of variants.

Development of a Rapid Model Generator Prototype.

When the complex process of simulating the real world production facilities is combined with the time consuming process of model building, more innovative and faster techniques of using simulation have to be adopted. It is with the specific purpose of increasing the speed and uptake of simulation models in industry that the use of generic simulation modules has been adopted.

A simulation module can be quickly created if it can be assembled by adding the building blocks (modules) in a model template. In order to develop a module that has the ability to be reused in different models under different conditions, the module must contain all if not most of the details and entities needed by the model. The collection and integration of the attributes, variables and entities in a logical way represents the method to create a generic simulation module. A module that is complete in all respect enables the modeller to use it in the model with little or no modifications. From the data collected it was found that the concept of 'model reuse' has gained momentum within the simulation modelling community. The concept of modellers being able to use and reuse models and modelling components developed by themselves, as well as others, thus saving time, money and effort was found to have certain merits. Also the technological advances which have been made over the years have now made this process a lot more viable and realistic.

In order to create a simulation model the modules are combined based on the needs of the end user. In the conceptual simulation model, model generation takes place when modules and data from an interface are added and assembled on the model template. For automatic generation of simulation model and making the simulation tool user-friendly, the functionalities within the simulation software is used and a secondary user interface built using Microsoft Excel is used for transferring data into the simulation software.

The modules created for this part of the study were a true representation of the components or the combination of components which are in use within the manufacturing system layouts identified in chapter four. To aid in creating the necessary modules a study was undertaken to identify the component or group of components which were found to repeat themselves in the layouts indentified. The results from this study was documented and used as the basis for single and combined module creation. However, this method of generic module creation needed expansion in the case of the RapidSim model as the modules developed for this part of the research were based on the cladistical analysis carried out in chapter 5.

From the information collected a comparison of the real world systems collected against how these potential systems could be built using the WITNESS simulation software package was undertaken. This exercise identified the different configuration of components which were being used in real world situations, with the information collected used in developing the modules which form the base of the template library. The process of constructing a module using the information generated in the cladogram takes place via a five stage process. The literature review also revealed that solutions, adopted by researchers and industries, are often customised to a very specific domain, and were developed to fit within the framework or programming paradigm of a particular commercial simulation tool. The implication is that additional work is often required to customise the template and that the models generated using the templates are generally limited to systems with regular patterns.

In order to facilitate the automatic generation of simulation models and for making the simulation tool user-friendly, a secondary user interface was built using Microsoft Excel to transfer the data into the simulation software. The use of a secondary user interface helps the modeller transfer the data required for model detailing, thus avoiding the time consuming process of creating and detailing all the entities (elements like machine, buffer, conveyor, etc.) of the model sequentially. By combining the various modules along with the data interface the user is able to create templates which can used on their own or combined together to form a larger simulation model. All of the modules are stored in a centralised file system or folder to facilitate easier and faster access to the information. The main objective of building of a library is to store the created modules, templates and interface and to make these items easily available and retrievable for use in generating the simulation model. This library equips the modeller with a set of pre-developed templates, modules and an excel driven interface which could be used to assemble a model quickly with little or no modifications.

Validation of the Template Based Approach

The work presented in this chapter detailed the work carried out in validating the design of the template based library and the external user interface. The interface validation was based on experimental testing and work in this chapter also highlighted the case studies which were used to test the interface and the analysed results which were obtained from those exercises. The overall method of validation as well as the overall discussion of the validation procedure was also discussed.

As no reusable templates were identified from the literature, a case study approach was used to evaluate the work done in development of the RapidSim model generator. The case study was structured into two distinctive parts or scenarios, with scenario 1 representing the creation of a simulation model using the manual modelling approach while scenario 2 represents the identical creation of a simulation model using the RapidSim approach. The independent variable which was manipulated and measured in this exercise was the use of the RapidSim interface as all aspects of both models will remained the same.

In scenario 1 the case study follows a model building exercise where the participants are given a structured model and asked to build said model using the conventional or manual modelling approach. The participant is expected to create the connections and logic necessary for the model by inputting them manually into the model. Scenario 2 is basically a repetition of the tasks carried out in scenario 1 but with the added use of the excel driven interface. The same parameters for the experiment are set and participants are given a structured modelling exercise to complete. The participant is given a short and concise tutorial to familiarise themselves with using the RapidSim interface lasting no longer than 5 minutes.

The results obtained from the experiments conducted as part of the validation exercise showed that the RapidSim approach to modelling has some significant advantages when compared to the conventional modelling approach. The use of the Excel driven interface showed that it was easier to create and run a model using RapidSim. In all aspects of the case study test the RapidSim interface was found to perform better than the conventional modelling techniques employed. The flexibility of using the RapidSim model was clearly visible from the data analysed as participants found the tasks of component creation, model re-arrangement, routing alterations, element bypass, introduction of breakdowns, linking and running the completed model to be easy and very easy when compared to the conventional modelling approach.

The most important fact gathered from all the tests carried out to validate the model was the reduction in the time taken to build and run the model. Analysis of the data showed that using the RapidSim approach led to a 65% reduction in the time taken to build and run a simulation model. The validation approach used for this part of the research was useful in determining the overall design and implementation of the user interface. It allowed transparent guidelines at each design stage, thereby reducing the unwanted need for over designed features and complex and illogical coding. It helped in developing an experimental testing procedure that was used to fully test the workings of the interface as well as determine how problems and changes to the system could be avoided or dealt with .

8.1.2 Strength of the Research Methodology

The research methodology possessed a number of strengths which were primarily driven by the use of work packages which detailed the deliverables at every stage of the research project and from the selection of the adopted method for data collection. Firstly as the project was divided into sub-sections it was easier to manage. The author was able to focus on the specific requirements for each individual work package, ensuring that the work set out in the package was completed correctly. As the work packages were built on top of each other it was necessary to complete a package before moving to the next as the work of the previous work package formed the basis for the work in the next package. This strategy facilitated a sequential progression to the development of the rapid model generator prototype. Information gathered on the respective organizational layouts were compared and contrasted in order to gain a wider understanding of the manufacturing industry and to also develop a classification system for manufacturing layouts.

Due to the quantitative and qualitative nature of the research it was necessary for the author to familiarise himself with the various methods which are used in the data collection process. It was proposed that several varying methods of data collection be used so as to ensure that the weaknesses of any particular method would not have any influence on the results obtained. As presented in chapter 3, the key data collection methods which have been used are the case study and the literature review.

The data collection process was continuous throughout the course of the research with the author continually assessing information collected from journal and conference papers as well as case studies. In order to clarify the information collected the author developed several different tabulated reports which validated the information collected throughout the research period. This process served as a check for the information collected, as only information which was relevant and useful to the research was stored in the tables. For the proposed case studies a range of manufacturing systems were identified in order to reflect the numerous types of manufacturing layouts that exist. From the information gathered, the author proceeded to construct a simulation case study scenario based on the development of a real world manufacturing layout. Close attention was paid to the relevance and requirements of the research whilst deciding on the case studies. The case studies were implemented with the main goal of minimising the author's ability to influence the participants.

The author spent a lot of time in developing and familiarising the tools for the RapidSim model generator whilst leaving the input processes to be managed by the respondents. The various approaches taken to the case studies during the validation process are considered to be suitable given the characteristics of the RapidSim framework

8.1.3 Main Contributions

The main contribution of the work carried out in this thesis is the rapid design of simulation models using cladistics and template based modelling. Cladistics was used to analyse data from the literature review resulting in the development of two distinct cladograms. Information from the cladograms was then used to develop the generic simulation modules. Rapid model generation is achieved through the use of the template based modules which are stored in a model library and an external based interface designed through Microsoft Excel. The model library facilitates the quick developments of models by providing access to readily available and reusable simulation components, whilst the user interface provides an easy means for the end user to assemble these templates into a completed simulation model.

8.1.3.1 Secondary Contributions

The work carried out during the course of this research resulted in a number of secondary contributionsto the field of simulation based template model development. The following are the secondarycontributions which have been made;

1) ***Reduction in the overall time needed to build a simulation model.*** The development of any simulation model, especially one which is built from scratch can be a very time consuming and labour intensive exercise. Using RapidSim the time taken to develop a model is significantly reduced as models are not required to be created from scratch but simply assembled from the pre-defined components which are set aside in the modelling library. Information gathered from the evaluation exercises all point towards a considerable increase in the speed in which simulation models can be built when using the RapidSim interface. The data also suggests that the model building process has become a lot easier when using RapidSim as opposed to the manual modelling approach. Results of the tests carried out using the RapidSim approach to simulation model building has clearly demonstrated that this approach leads to a significant reduction in the time taken to create a model. In most cases there is a 65% reduction in the time needed to build a simulation model.

2) ***Reduction in the level of skill needed to build a simulation model.*** One of the most important factors to consider in any simulation modelling exercise is the human factor. Simulation model developers require certain skills, in conceptual modelling, validation and statistics as well as being versed in the use of the software package needed to develop the model. Modellers must also possess the skill of dealing with people as this helps in facilitating the data collection process. This level of expertise does not come cheap but with RapidSim this cost can be significantly reduced. Modellers need not be experts when using the RapidSim approach as it is designed for both experienced and non experiencedusers. As the RapidSim interface designed is to be user friendly it is very easy for non-simulation professionals to quickly and efficiently create a simulation model. Persons with little or no expertise in the field of simulation or modelling can create a completed, ready to use model in a relatively short period of time.

3) ***The development of a neutral template based modelling library***. The most important concept of the RapidSim modelling approach is the use of pre-built ready to use templates which can be used on their own or in combination with other templates to quickly design, assemble and run a simulation model. The developments of generic modules which can are reusable is one of the key contributions to this research, as the modules developed no longer need to be designed for a specific layout or purpose. One of the most important aspects to this approach is based on the models level of repeatability. Modules can be used and reused within any simulation model thereby eliminating the need for continuous design or redesign. As modules are made up of various combinations of simulation components (machine, buffer, conveyor etc.) building a model is as easy as selecting the modules which represent the components used in the system and simply assembling these modules in a template to form the completed model. As the templates developed are neutral and not designed for any particular manufacturing system this helps in facilitating their reuse in various manufacturing systems..

4) ***The creation of an external based interface "RapidSim".*** The development of an external interface which has been created in Microsoft Excel and which is used to drive the Witness simulation engine. This tool has been developed as a direct response to the challenges faced by simulation modellers when attempting to develop a rapid simulation model. The main focus of the tool has been in reflecting the influence which template based modelling and template based libraries can have on the overall simulation modelling process. Some of the key features of the rapid modelling tool include rapid model development, generic module creation, rapid and easy model manipulation, simplified data collection and improved ease of use. The RapidSim interface was developed with the aim of making simulation modelling faster and easier to use. The interface has been designed using Microsoft Excel and has been programmed using Visual Basic. The design of the interface is aimed at giving users an easy approach to the selection and modelling of layout types. The RapidSim interface allows for the easy creation, modification and running of a simulation model. Users need not have any previous knowledge of simulation modelling in order to use the interface.

5) ***The creation of generic modules which can be reused in different manufacturing layout.*** A simulation module can be quickly created if it can be assembled by adding the building blocks (modules) in a model template. In order to develop a module that has the ability to be reused in different models under different conditions, the module must contain all if not most of the details and entities needed by the model. The collection and integration of the attributes, variables and entities in a logical way represents the method to create a generic simulation module. The module must be able to store data such as routing commands, input and output rules, programming logic and it must also be able to handle the automatic connectivity that takes place between moduleswhen they are used ontheir own or in combination with other similar or dissimilar modules to create a completed model. The modules ability to store data can be seen as the most important aspect of its creation as this data will help in facilitating the overall model building process. The developments of generic modules which can

are reusable and repeatable is one of the key contributions to this research. The modules developed no longer need to be designed for a specific layout or purpose as the modules can be adapted with little or no modifications to work in different manufacturingenvironments.

6) ***The manufacturing layout type cladogram and the system component cladogram.*** Using cladistics it was possible to detail the way in whichmanufacturing layouts as well as their components have evolved. The information collected and analysed on the various manufacturing types that exist produced a cladogram with 3 distinct groupings based on the manufacturer's volume of production. Manufacturing system types belonged to either a low volume, a medium volume or a high volume production system. From the cladogram it was established that all production systems to date emerged or evolved from a fixed position layout and as resources increased, progressed to a traditional job shop production system. As technology and the use of computational resources increased along with consumer demand, the layouts used in the manufacturing processes also evolved. The combined component type cladogram showed that components used in the manufacturing environment started out as single elements but as time went by they evolved into various combined component types. From the cladogram of combined component types, components were all considered to be active and to be derived from a resource. The logic rules which were used for modelling single elements also evolved as the component type evolved, with the rules becoming more complex as the complexity and functionality of the combined components increased. From the data analysed it was found that certain repetitive patterns were becoming more frequent and in use throughout a number of different manufacturing systems. For examplethe use of a machine combined with a buffer (manual or automatic) or the use of a machine combined with a conveyor was found to exist in a number of the manufacturingsystems identified in the system type cladogram. Since cladistics can be used to identify the current layout variants / families and groups, it can also provide guidance for deciding upon the relevance of a new layout within an existing group / family of variants. Having this classification

scheme in placecan help in expediting the simulation model building process, as templates within the modelling library can be built with a specific group of layouts in mind.

7) ***A classification of manufacturing systems layout types***. This newly developed classification looks at the most relevant system layouts which are being used in the manufacturing industry to date. A total of 11 different layout types were identified and used in construction of the classification. After research and analysis into the different manufacturing systems types identified in the review, an attempt has been made to identify the commonalities and differences which some of these systems may possess and to display this data in the form of a classification system. Review of the literature showed that although the use of machines, buffers, conveyors, workers and the quantity or volume of production were present in most of the systems identified these factors alone were not enough to formulate a classification. As the classification was based on the layout types identified from the literature review it was only fitting that the characteristics which make up these various layouts form the differentiating basis for the classification. The total number of characteristics identified came to 14 and included characteristics such as dedicated cells, product flexibility, sequential part movement and automatic machine changeovers etc.

The information presented in figure 46 below shows the key issues raised from the literature, the gaps in the knowledge and the key contributions made.

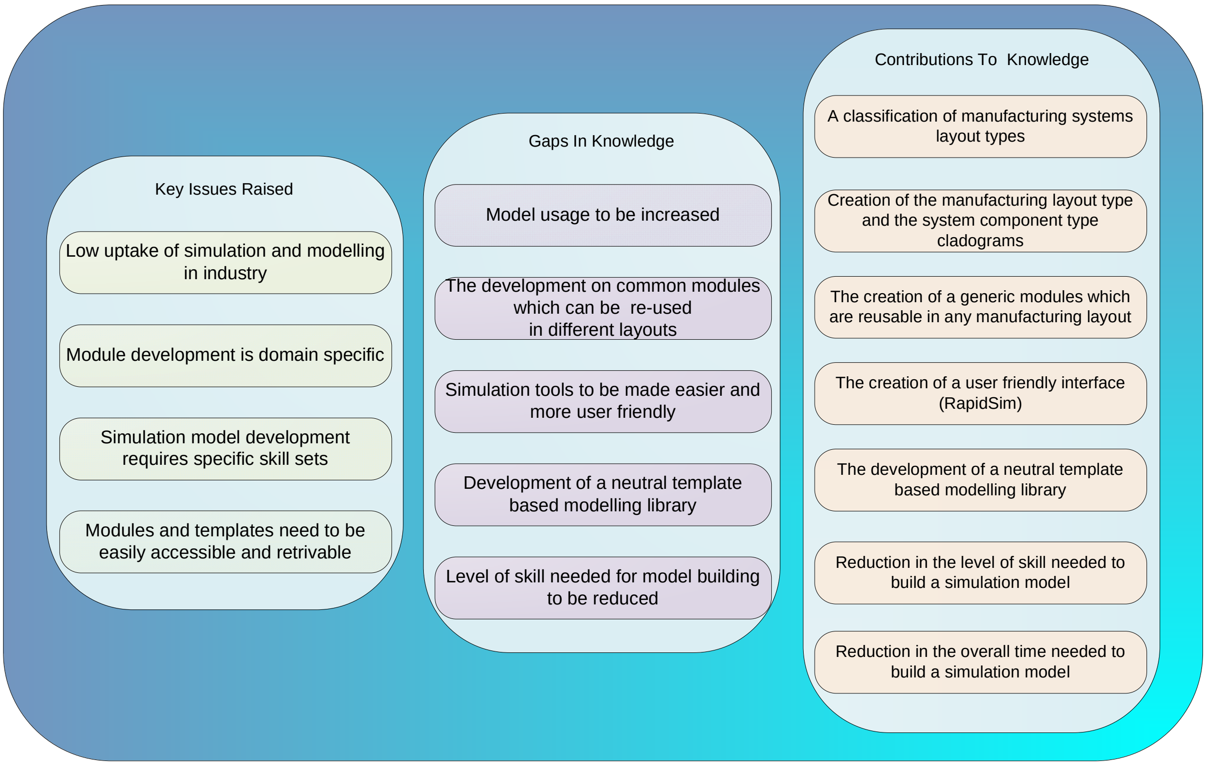


Figure 46: The contributions to knowledge

8.1.4 Limitations of the Research

The work presented in this section of the thesis discusses the limitations of the research in regard to the adopted research methodology and findings. The limitations of the methodology are considered in regard to the quantitative research carried out and the case studies presented.

The use of quantitative research as the sole means of gathering data brings with it certain drawbacks which can hamper the research process in terms of data validity. Quantitative research methods allow the user to collect a much narrower and sometimes superficial dataset. The results obtained from quantitative research tend to be more numerical in description rather than narrative and this posed a problem when researching into the manufacturing layout types. Also the research carried out was done in an unnatural and artificial environment with a level of control being applied to the data collection exercise. This level of control may not normally be in place in the real world and can lead to the generation of laboratory results as opposed to real world results. Finally the development of standard questions by researchers can lead to 'structural' bias and false representation, where the data actually reflects the view of them instead of the participating subject.

The results generated from any given case study are driven by the perception and behaviour of the participants involved. With any case study approach there is always the threat that the results obtained are not a true representation of the views of most people as individuals all tend to have their own biases. The duration of each case study varied due to the ability of the participant. At this timethe author attemptied to minimise his influence during the data input process and only provided assistance when it wa sneeded. The timeframe for the case studies was determined by the availability of resources as well as the availability of participants. As the respondents taking part in the validation case studies had very busy schedules a pro-active approach was taken in order to maximise their available time. This approach consisted of four activities which were carried out by the author prior to and after the case study activity. Firstly the participant was given a copy of the case study beforehand so as to familiarise themselves with the case. Secondly the author demonstrated the interface beforehand in order to clarify any potential misunderstandings that could arise. Thirdly the author supported the data input process if it was required by the user and fourthly following up and understanding the results obtained from the case studies carried out.

In addition to the research methodology and case study approaches discussed above, potential limitations to the research and are as follows;

Range of Manufacturing Systems: From the investigation into the manufacturing system types a total of 11 manufactring systems were identified. These layout types represented the most common used systems and component configurations in the manufacturing industry to date. However it should be noted that the literature review also identified other manufacturing systems exist and which are not as common as the ones mentioned in this thesis. Some examples of these systems includes multi channel manufacturing, quasi continuous manufacturing, packaging lines and conveying transport systems. Further research is needed into these systems as data on these sytems was not readily available and as a result they were dropped from the list of manufacturing system types.

The Chosen Characteristics: A total of 58 chaacters were identified as belonging to the manufacturing system type cladogram while a further 47 were identified as belonging to the combined component type cladogram. The characteristics chosen for the system type cladogram were based solely on the production requirements of the manufacturing systems identified. With this in mind only the functional requirements were considerd as characteristics and all othere characters were discarded. One of the limitations of this research is that it did not focus on non functional characters which could act as further differentiators in the cladogram building process. Characteristics such as division of labour, operator based machine maintenance, sequential dependence on workers, job rotation and line balancing need to be given further consideration. Similarly the characteristics chosen for the component type cladogram were based solely on their functional and model building capabilities. Characteristics outside of these requirements such as standardisation of assembly times, agile automation for different products and preventitive maintenace should be given furth consideration.

Level of Model Details and Modelling*:* One of the limitations to the work carried out in this thesis relates to the level of detail in the replicated models. Models which are created via the RapidSim approach are generated with only the basic information needed for them to work. The user still needs to modify the constructed modules and model to meet their specific requirements.

Level of Model Complexity: The RapidSim approach to model development focused primarily on the rapid construction of simulation models through the use of template based modelling. Another limitation to this research is that the models constructed by this method are not very complex. While modules comprising of robots and agv's can be mnodelled easily by RapidSim, some modification is needed by the end user to increase their complexity.

Accuracy of the Models Developed: Another limitation to this thesis relates to the accuracy of the models developed. While RapidSim can be used to replicate models quickly the accuracy of the models developed can be improved. Models built with RapidSim are reliant on the data supplied aand inputted via the RapidSim interface. Improving the interface so that it can handle more detailed data needed for model construction can help improve the model accuracy.

The Developed Cladograms: The cladograms developed were based on the characteristics identified from the literature review. As mentioned above the list of characters identified could be widened to include characters that were not included in the review thereby altering the end cladograms. As the cladograms developed were based on some degree of subjectivity on the part of the author this could also influence the final cladograms.

Some other limitations that have been noted are;

1) The data collection process needs to be widened to include data collected from experts in the field of simulation and modelling. This will be discussed further in the recommendations section of this thesis.

2) The range of testing for the RapidSim interface could be wider. Potential solutions to this problem will be detailed in the recommendations section of this thesis.

3) The time taken to construct a model. Again this could be improved and will be detailed in the recommendations section.

8.2 Recommendations for Future work

This thesis has presented an evolutionary approach to the rapid design of simulation models through the use of template based modelling. The field of simulation and modelling is gaining increasing interest in both the manufacturing and non-manufacturing sectors. The exploration of template based modelling as a means of increasing the speed and uptake of simulation in industry is gaining ground as researchers are now looking beyond the traditional approaches in this area. The work presented in this section aims to give a view as to how the rapid modelling approach can be improved and further developed and how these changes can be applied to a wider range of simulation modelling problems.

A number of recommendations can be made for the future development of the RapidSim and template based modelling approach;

- Evaluation of system and task complexity
- Informational content and detail
- Usability trials
- Introduction of CAD data
- Integration of key performance measures
- Using cladistics to map process flows

Evaluation of system and task complexity:

It is necessary that an evaluation of both the system and task complexity be undertaken so as to ensure the correct level of user participation is achieved. If either the system or the task is too complex for the user to understand it is essential that a high level of user participation is sought. However if the situation becomes reversed and the system becomes less complex, minimal user participation may be required, especially if the task being undertaken is well documented. Achieving the correct mix of system and task complexity is essential for ensuring user participation.

Informational content and detail

System and task complexities aside, the developer should make the greatest effort when designing the usefulness of the application. One of the ways this can be achieved is by ensuring that the application contains the right information or mix of information in regard to the content and the level of detail needed to use the application. Having the might informational mix can aid users when performing their tasks leading to an increase in the level of job production.

If the level of user participation is relatively high then it may become necessary for the developer to employ some measure of one to one interaction between themselves and the intended users. This approach is aimed at getting the best possible result from the user participation. Also it is important that the developer / user interaction be developed over time so as to facilitate greater feedback. User feedback is the key to obtaining the right informational mix. However if the level of participation become substantially lower it may become necessary for the developer to undertake some form of group review so as to ascertain if the applications content and level of detail are correct.

It should also be understood that user participation should be effective with any conflicts that may arise dealt with swiftly and efficiently. When a user raises an issue in regards to the prototype and it's usage the developer should ensure that every effort is made to respond to the questions posed.

Design based on user abilities

When designing a user based interface it is necessary to employ experienced interface designers that follow the standard guidelines set by industry so as to ensure that the user interface designed matches the intended users abilities. The user interface needs to be constructed in such a manner that it aids users in developing a mental picture of the system they are attempting to model, by strengthening the factors that support the process and impeding those that dont.

In order to lessen the effect of the user’s computer anxiety on the ease of use perception it is advised that a one to one developer / user based relationship be developed. This interaction is geared towards obtaining a certain degree of interaction between the task requirements, the user’s ability and the functionality of the technology being tested, in this case the RapidSim interface. This interaction can be informal and a relationship developed between the two parties which are built over time facilitates good feedback.

Furthermore the application should be designed in such a manner that it is easy to use by most if not all members or operators in the workplace. The applications ease of use should be an appealing factor to even the most computer anxious users or operators. The manufacturing companies which use this interface should provide their operators with some basic training in using the interface so as to familiarise themselves with its strengths and weaknesses. However, individual users who are not fully confident in the use of the interface should be given one to one session’s to dispel any problems they may have.

If it turns out that the intended user population is not computer anxious, the developer will have to expend significantly less effort in bringing the interface to the masses. In this sense the developer can focus less on the interface’s ease of use and more on its functionality as experienced users tend to attach less importance to a programs ease of use. However the developer should strive to make the interface as easy to use as possible.

Usability trials

As with all systems that are developed only a handful of persons are exposed to the design and development process. With this is mind it is paramount that the interface be put through a usability trial with the main aim being the detection of potential problems. The usability trials should be devised in a manner that replicates both realistic and relevant work situations and in most instances it should be devised after consultation with the end user. When conducting these trials it is important that the developer be present so as to observer the manner in which participants interact with the interface and to also provide guidance if needed. This exercise allows the developer the unique opportunity to collect data on potential problems so that the necessary changes can be made to the interface so as to increase the users end performance.

The scope of the trials should also be widened to include both expert and non-expert users in the field of simulation and model building. As the interface was not tested under real work conditions and without the input from any experts in this field, it is imperative that this form of testing be carried out.

Introduction of CAD data

Use of the RapidSim interface has demonstrated that by inputting the proposed co-ordinates of the selected components onto the modelling window of the interface, the component position can then be transferred onto the main witness modelling window when the model is created. This transfer of the component position has led the author to identify an area in which this process can be further refined. As with most production and manufacturing systems the layout in regard to machine positioning is usually done via a CAD package. The CAD files which stores this data is usually made up of a co-ordinate measurement system which stores the component or machine position as an X and Y co-ordinate.

It may be the case that the co-ordinates taken from the CAD file can be transferred onto the main witness modelling window when the model is created, thereby positioning the components exactly as they are specified in the layout drawing. It may also be worthwhile to investigate whether the CAD layout can be stored as a module which can then be recalled if and when needed by the modeller. This module can be super imposed onto the witness screen to give a 3D representation of the model being developed.

Integration of key performance measures

The work done so far in creating ready to use templates has shown that although these templates can be made readily available and that models can be created quickly there still needs to be some form of input from the end user. The author proposes that further work can be carried out in developing the key performance measures which are available on the witness demo page. Currently data is inputted into the interface and then transferred into the main Witness modelling window via the create model button. Some key performance measures such as capturing the machine utilisation still needs the user to perform a sequence of remedial steps before the model can be run.

The author proposes that an investigation be carried out so to ascertain if and how the data needed for measuring the key performance indicators can be inputted via the interface instead of the main Witness page. This would give the end user more simplicity as all the modelling and data capture can be done via one program instead of two.

Using cladistics to map process flows

During the course of this research the author has demonstrated that the process of cladistics can be successfully used in order to trace the evolution and the development of manufacturing systems. The focus during the course of this research has been on tracing the evolution of manufacturing systems as well as their components. However work done through via the literature review has identified the possibility that systems and components can be mapped according to their process flow using cladistics. This is a relatively new field as recent work carried out by AlGeddawy and ElMaraghy in 2009 and 2011 respectively in the field of delayed product differentiation shows Theuse of cladistics to map process flows can be used in determining the best possible or the most optimum physical position of machines and transport systems within a given layout.

8.3 Conclusion

This thesis has detailed the evolutionary approach to the rapid design of simulation models through the use of cladistics and template based modelling. The work carried out has achieved all five of the objectives that have been outlined in chapter 2 of this report. The following points demonstrate how these objectives have been met.

Research has been conducted via a literature review into the state of the art in simulation model development and template based modelling. As part of the review the various simulation modelling approaches which are currently being used have been examined and a comprehensive review of the current techniques in this field has been undertaken. A detailed assessment of the literature available in this field has been carried out with the information collected and documented in both text and tabular form, including the log of key word searches and the key publications identified. The area of manufacturing systems layouts and their relevance to the field of simulation and model building has also been explored. As a direct result of this review it was possible to identify the gap in the current research as it pertains to the rapid development of simulation models. It was evident from the data collected that any new approach to the process of rapid simulation model design could benefit from an improved classification of manufacturing layout types. In order to achieve the first objective the author completed the following;

- Developed a comprehensive list of manufacturing system types based on the type of layouts used.
- Developed an initial classification system based on manufacturing systems layout types.
- Validated the proposed classification so as to provide a comprehensive base from which to build on.

The use of cladistics and evolutionary analysis as the tools for classifying the manufacturing layouts brought with it certain challenges. As this was a new approach and an entirely new field of study the author had to become familiar with the study of cladistics and how this could be used as a classification tool. To aid the author in the study of cladistics a detailed assessment of the literature available in this field was undertaken with particular reference to the use of cladistics within the manufacturing sector. During the process of classifying the layouts it became evident that not one but two cladistical classifications were needed in order to progress to the design of the model library. The cladistical analysis of the data identified that layouts belonged to three distinctive groupings based of their particular levels of production. In order to achieve the second objective the author completed the following;

- Identified from the literature the 58 characteristics which were used to classify the manufacturing systems layouts.
- Identified from the literature the 42 characteristics which were used to classify the system component types.
- Developed the data matrix of manufacturing layout types.
- Developed the data matrix of system component types.

- Developed the cladogram of manufacturing systems layout types.
- Developed the cladogram of system component types.
- Provided a detailed analysis of the cladogram data.

The use of cladistics to classify the data collected meant that the author had to determine a means of converting the cladistical data into usable data which could be used in construction of a simulation module and model. Identification of the repeatable patterns of components led the author to compile a tabulated comparison of the real world manufacturing layouts and their component verses their witness equivalent. This exercise identified the component or groups of components that were used in construction of the simulation modules. However, this method of module creation needed expansion in the case of the RapidSim model as the modules developed for this research were generic and repeatable.In order to achieve the third objective the author completed the following;

- Developed a method for construction simulation modules from cladistical data.
- Developed a generic and repeatable simulation module which could be used in any manufacturing layout.
- Provided a detailed comparison of real world manufacturing systems verse their Witness equivalent.
- Developed a means of interconnecting modules with all the necessary logic pre-loaded into the module
- Creation of a model based simulation template.
- Development of the neutral model library of simulation modules and templates.

The development of a rapid model generator using a discrete–event simulator, whereby these components are retrieved from the model library has been key to the success of this research. The process of developing the RapidSim interface required the author to become familiar with the use of Microsoft Visual Basic programming and the Witness command language as a combination of these programming languages was used to program the interface. The interface has been designed in such a way that the information inputted into the main interface window is transferred directly into the main Witness modelling page. This approach has been modified so as to allow the interface to drive the simulation based engine. In order to achieve the fourth objective the author completed the following;

- Enabling the interface to drivethe simulation engine. The witness model page is only opened when the create model button on the interface is engaged.
- Development of a centralised file system which facilitates the easy retrieval of simulation modules.
- Development of the RapidSim interface.
- Making the interface easy to use.
- Increased the speed of simulation model building.
- Creation of a generic witness modelling page which contains all the relevant data and logic for any generic model already pre-loaded into the page.

The proposed approach to rapid model development has been validated using a two way case study approach. The case studies are based on real world systems and as such they start off being simple and get progressively more difficult as the case progresses. An incremental approach was followed for validation, whereby the author engaged with the persons involved in the use of the interface. The results obtained from the validation process shows that the proposed evolutionary approach to simulation models can model simple as well as complicated manufacturing scenarios. The validation process has demonstrated that by using the RapidSim approach the speed at which the model building process takes place has dramatically increased. Also the ease of use of the interface has also been demonstrated.

The research carried out in completion of this thesis provides a solid foundation for further development of the template based modelling approach as a means of filling the simulation gap within the manufacturing sector.

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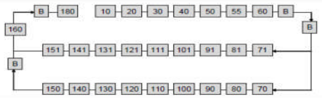
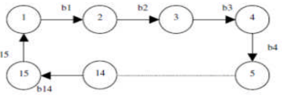
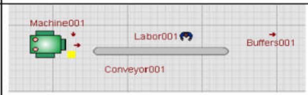
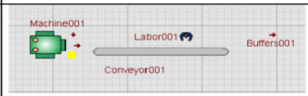
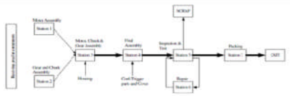
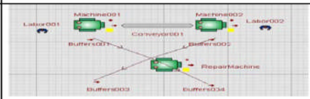
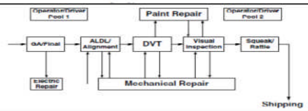
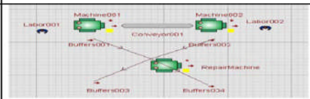
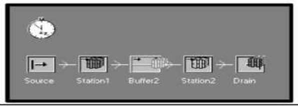
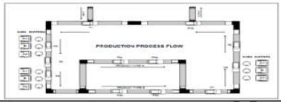
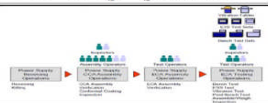
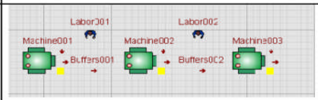
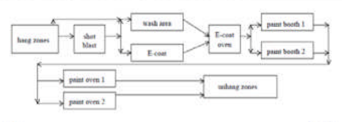
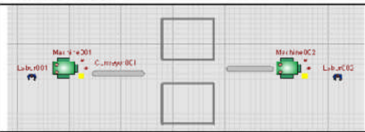
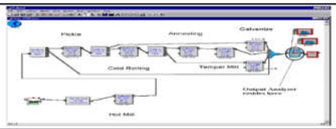
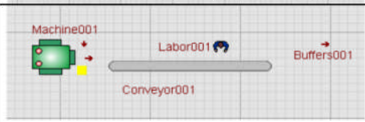
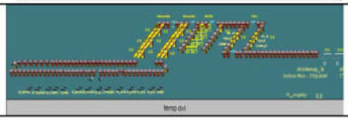
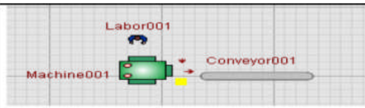
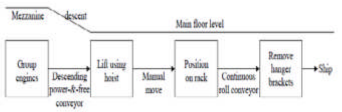
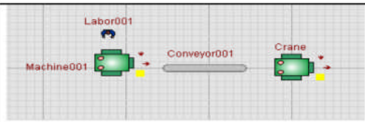
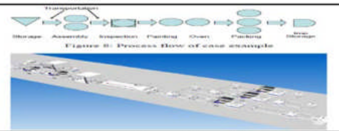
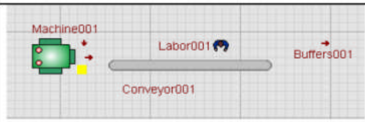
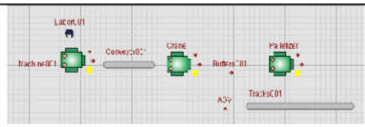
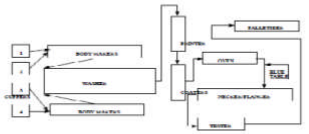
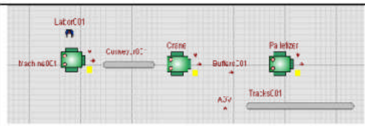
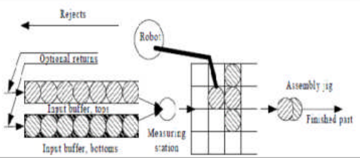
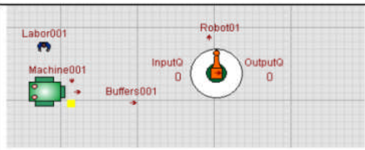
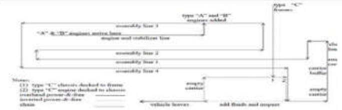
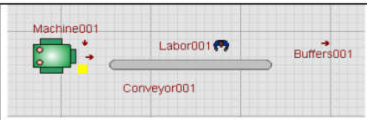
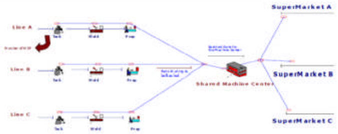
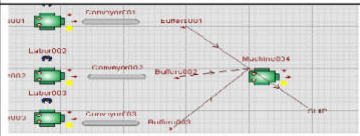
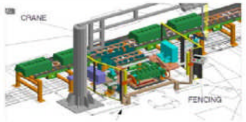
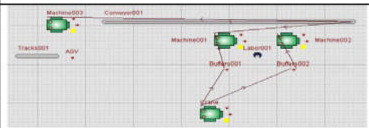
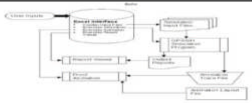
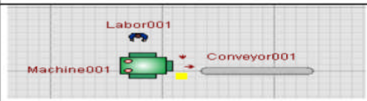
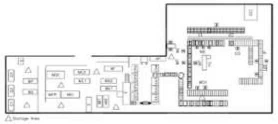
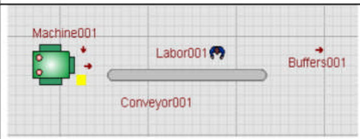
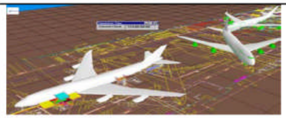
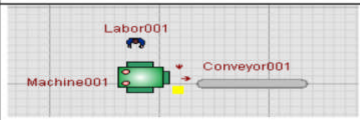
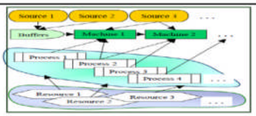
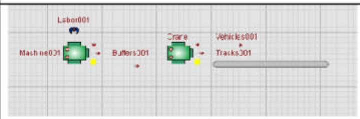
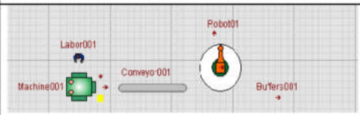
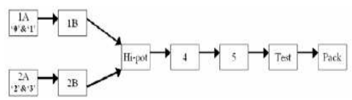
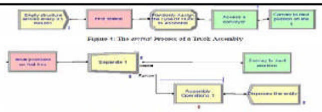
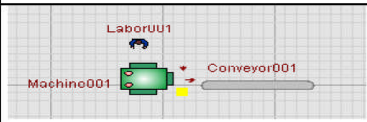
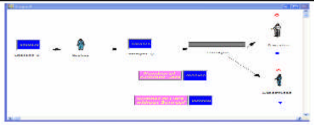
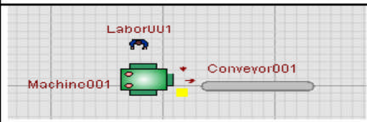
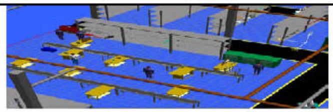
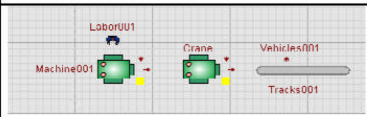
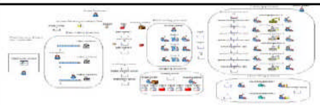
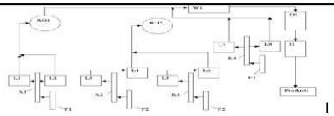
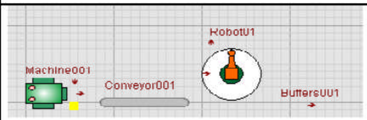
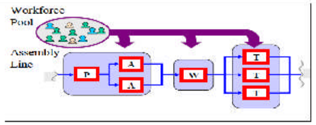
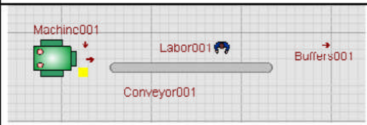
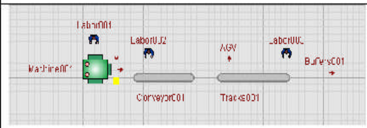
APPENDIX 1: REAL WORLD LAYOUTS & THE WITNESS EQUIVALENT

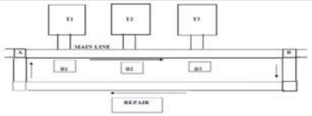
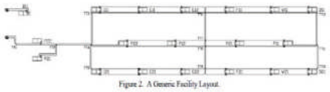
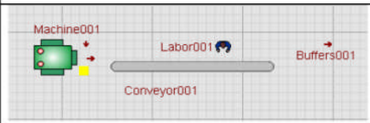
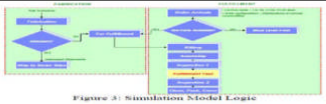
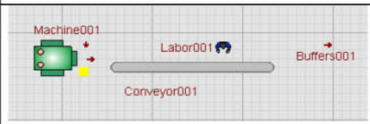
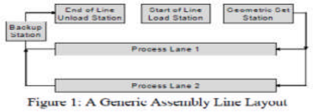
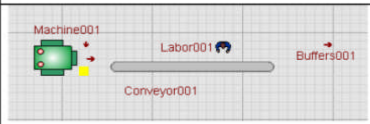
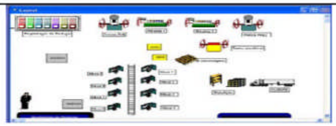
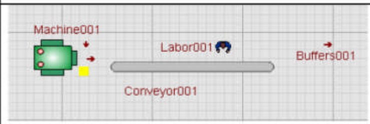
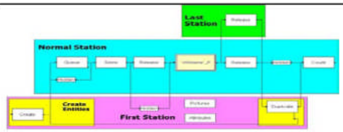
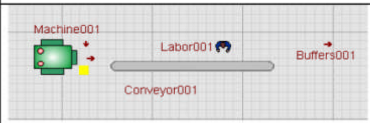
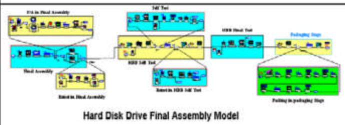
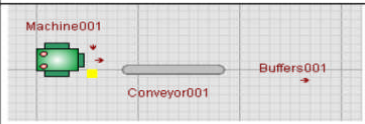
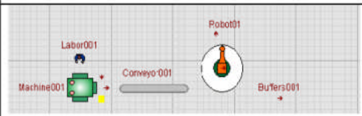
: Real World Systems vs. the Witness Equivalent

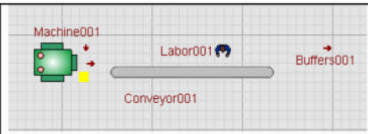
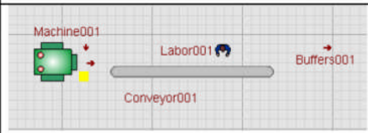
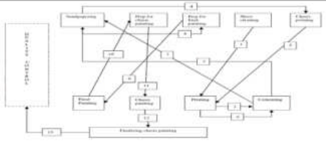
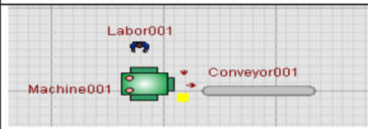
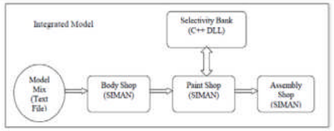
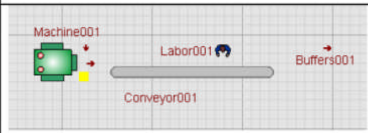
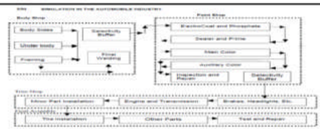
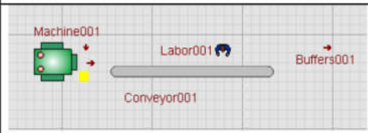
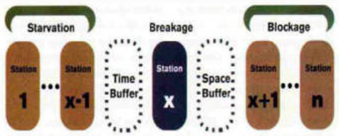
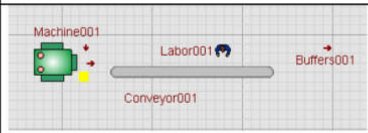
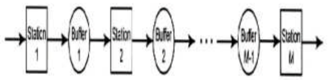
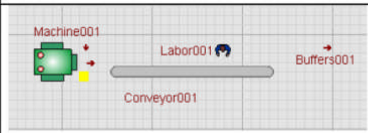
Author	Model Taken from Literature Review	Witness Model	Witness File
Shin et al (2004)	 Assembly Line Machines, Conveyors, Buffers & Labour		Witness components Machine Conveyor Labour, Buffer
Altiparmak et al (2002)	 Assembly Line Machines, Conveyors, Buffers		Witness components Machine Conveyor Labour, Buffer
M.Anderson & G.Olsson (1998)	 Assembly Line Machines, Conveyors, Buffers & Labour		Witness components Machine Conveyor Labour, Buffer
D.Kibira & C.McLean (2002)	 Assembly Line Machines, Conveyors & Manual Buffers		Witness components Machine Conveyor Labour, Buffer
V.Patel & J.Ashby (2002)	 Assembly Line Machines, Conveyors, & Labour		Witness components Machine Conveyor Labour, Buffer
T.Schulze & M.Schumann (2000)	 Assembly Line Machines, Conveyors, Buffer & Labour		Witness components Machine Conveyor Labour, Buffer
R.Al-Aomar (2000)	 Assembly Line Machines, Conveyors, Buffers		Witness components Machine Conveyor Buffer
K.Springfield et al (1999)	 Assembly Line Machines, Buffers & Labour		Witness components Machine Labour, Buffer

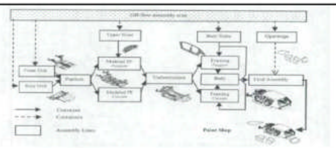
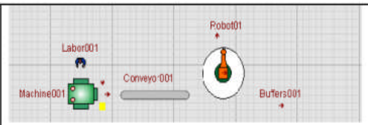
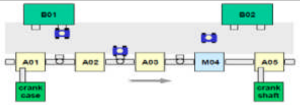
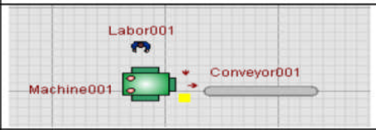
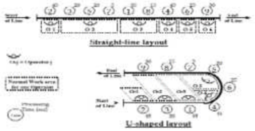
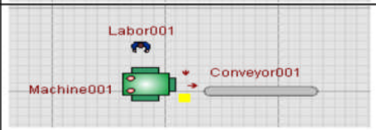
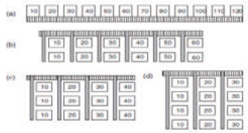
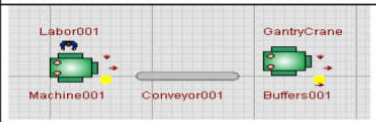
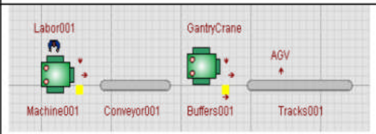
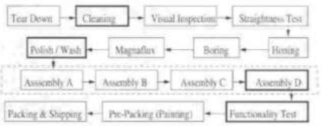
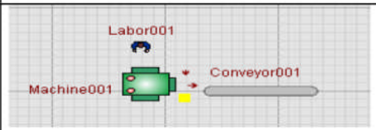
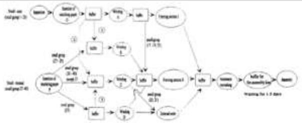
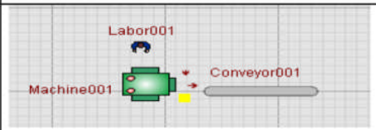
Author	Model Taken from Literature Review		Witness Model	Witness File
E.Williams & S.Sadakane (1997)		Assembly Line Machines, Conveyors, & Labour		Witness components Machine Conveyor Labor Power & Free / Carousel
P.Mullarkey & S.Gavirneni (2000)		Assembly Line Machines, Conveyors, Buffers & Labour		Witness components Machine Conveyor Labour, Buffer
Fields et al (2000)		Assembly Line Machines, Conveyors, & Labour		Witness components Machine Conveyor Labour,
E.Williams & D.Orlando (1998)		Assembly Line Machines, Conveyors, & Labor & Crane		Witness components Machine Conveyor Labor Crane
Heilala et al (2008)		Assembly Line Machines, Conveyors, Manual Buffers & Labour		Witness components Machine Conveyor Labour, Buffer
Moris et al (2008)		Assembly Line (Volvo Sweden) Machines, Conveyors, Buffers, Labour, AGV'S, Palletizer, Gantry Cranes		Witness components Machine Conveyor Labour, Buffer AGV'S, Tracks, Palletizer, Gantry Crane
M.Grabau & R.Maurer (1997)		Assembly Line Machines, Conveyors, Buffers & Palletizer, Crane		Witness components Machine Conveyor Buffer Palletizer, Gantry Crane
A.Thesen & A.Jantayavichit (1999)		Assembly Line Station Machines, Buffers ,Labour, Robot		Witness components Machine Buffer Labour Robot

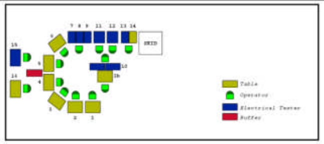
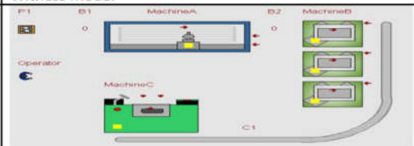
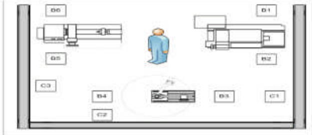
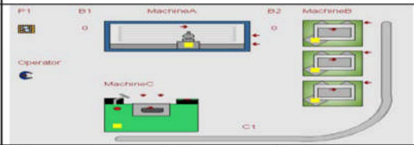
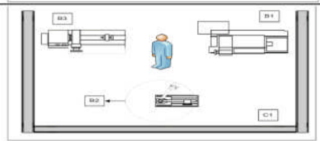
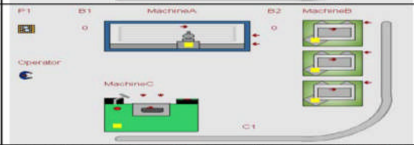
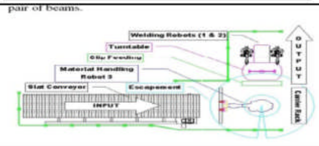
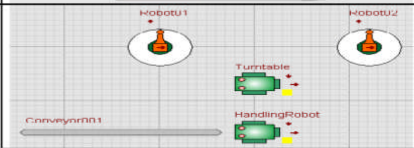
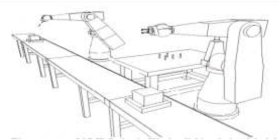
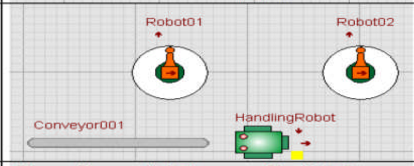
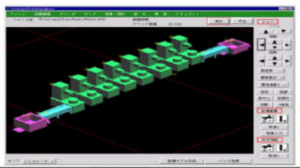
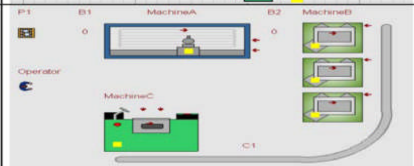
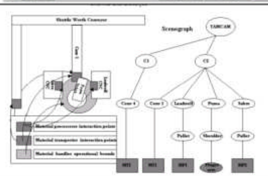
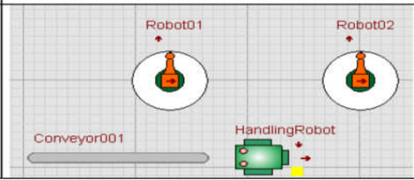
Williams and Celik (1998)		Assembly Line Station Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Knoll & Heim (2000)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machines Conveyor Labour, Buffer AGV, Tracks, Crane
R.Khanolkar (2000)		Assembly Line Machines, Conveyors, Buffers, Labour, Shuttle, Crane, articulating arm		Witness components Machine Conveyor Labour, Buffer AGV'S, Tracks, Palletizer, Gantry Crane Possible Robot
G.Rehn (2000)		Assembly Line (Painting at John Deer Machines, Conveyors, Labour		Witness components Machine Conveyor Labour,
Silva et al (2000)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Lu & Sundaram (2002)		Assembly Line Machines, Conveyors, Labour		Witness components Machine Conveyor Labour,
Lu et al 2003		Assembly Line Machines, Buffers, Labour, Cranes, Dollies		Witness components Machine Buffer Labour, Crane Vehicle and Track
Han et al (2003)		Assembly Line Machines, Conveyors, Buffers, Robots, Labour		Witness components Machine Conveyor Buffer Labour, Robot

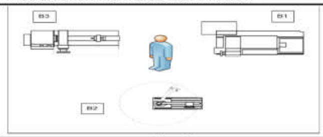
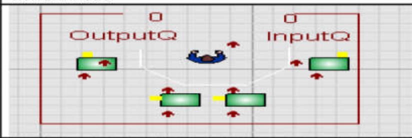
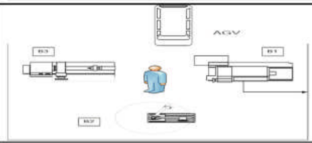
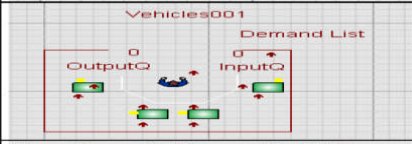
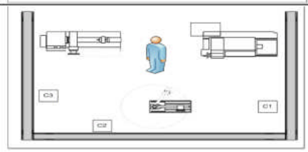
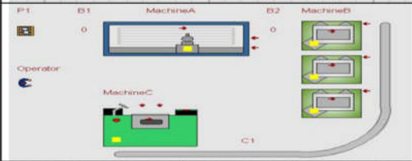
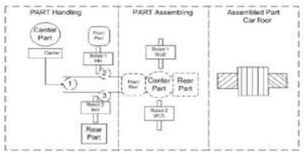
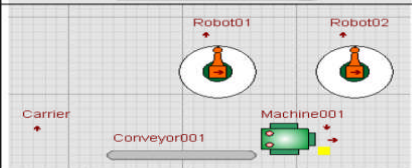
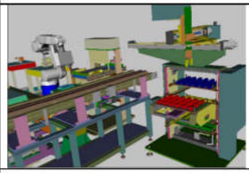
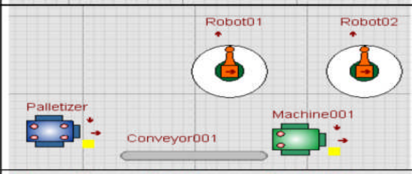
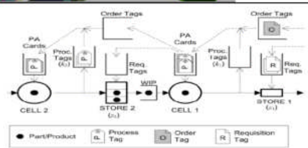
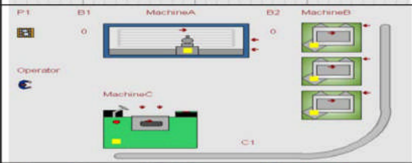
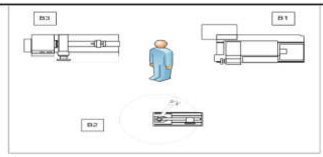
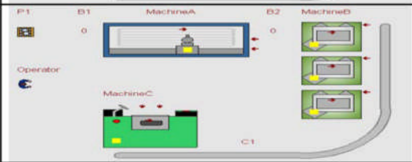
Ali et al (2005)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Lee & Luo (2005)		Assembly Line Machines, Conveyors, Labour		Witness components Machine Conveyor Labour,
Yu et al 2006		Assembly Line Machines, Conveyors, Labour		Witness components Machine Conveyor Labour,
Longo et al		Assembly Line (Heater Manufacture) Machines, Labour, Dollies. Overhead Crane, Manual Transport system		Witness components Machine Labor Vehicle and Track, Crane
Aguirre et al (2008)		Assembly Line (SIMUL8 Model) Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Ali & Chen (2008)		Assembly Line Machines, Conveyors, Buffers, Robots		Witness components Machine Conveyor Buffer Robot
Noack & Rose (2008)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Hasgul & Buyuksunetci (2005)		Assembly Line Machines, Conveyors, Buffers, Labour, AGV'S		Witness components Machine Conveyor Labour, Buffer AGV & Track

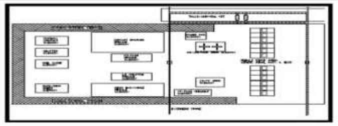
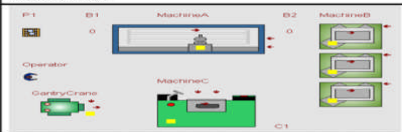
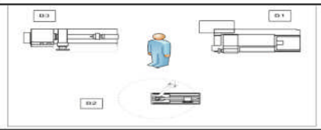
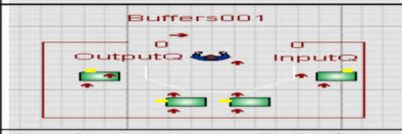
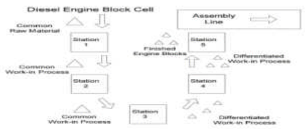
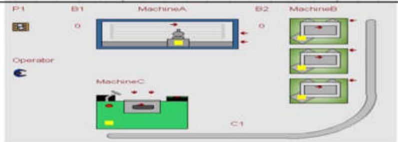
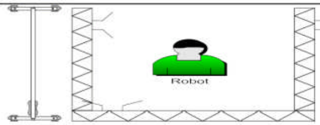
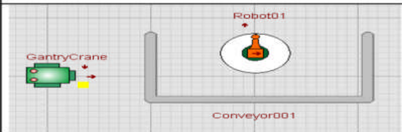
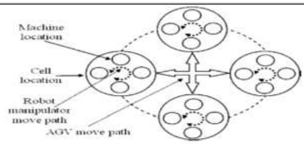
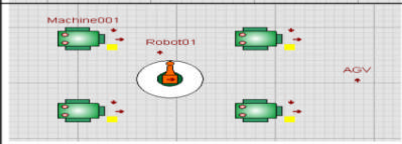
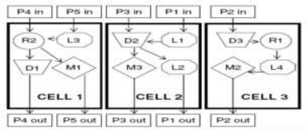
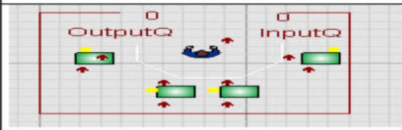
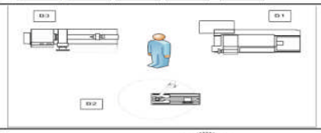
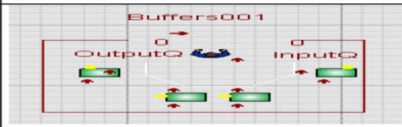
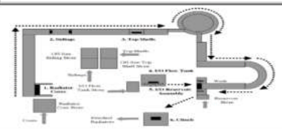
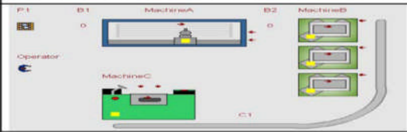
Jayaraman & Gunal (1997)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Mackulak et al (1998)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Ramakrishnan et al (2008)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Manassa et al (2004)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Montevechi et al (2007)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Treadwell & herrmann (2005)		Assembly Line Machines, Conveyors, Buffers, Labour, Rework station		Witness components Machine Conveyor Labour, Buffer
Ali & Souza (2007)		Assembly Line Machines, Conveyors, Buffers		Witness components Machine Conveyor Buffer
Harrell & Gladwin (2007)		Assembly Line Machines, Conveyors, Buffers, Labour, Robots		Witness components Machine Conveyor Buffer Labour, Robot

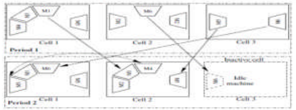
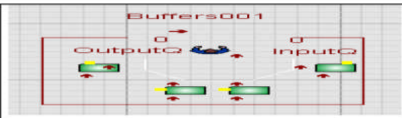
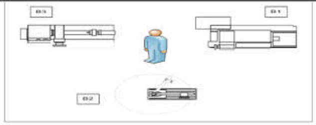
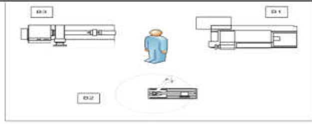
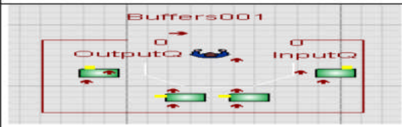
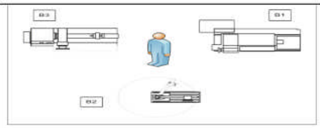
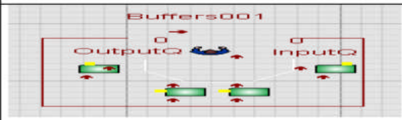
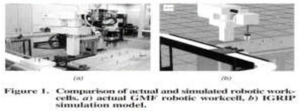
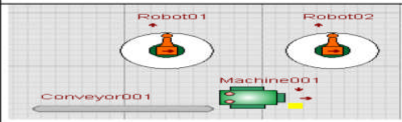
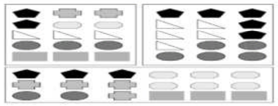
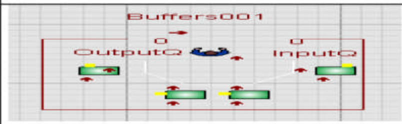
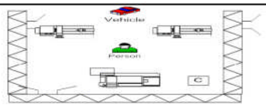
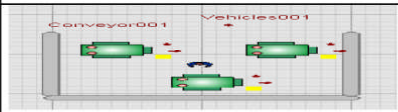
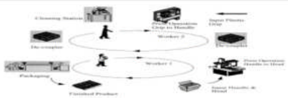
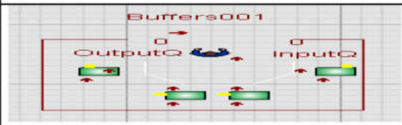
Ingemansson & Oscarsson (2005)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
M.Seppanen (2005)	 Figure 1: Assembly Line Flow Diagram	Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Dengiz & Belgin (2007)		Assembly Line Machines, Conveyors, Labour		Witness components Machine Conveyor Labour,
Park et al (1998)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Ulgen & Gunal (1998)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Umble et al 2000		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Alden et al (2006)		Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer

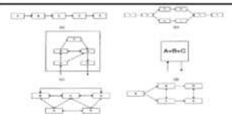
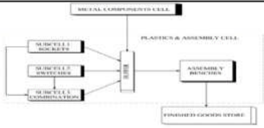
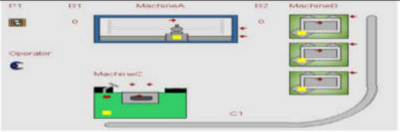
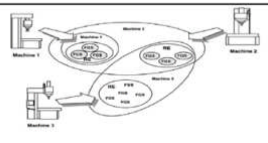
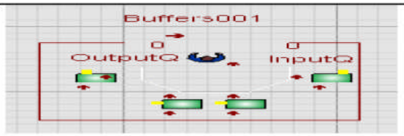
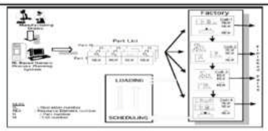
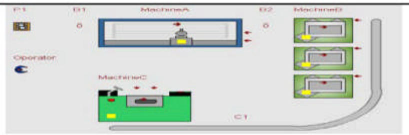
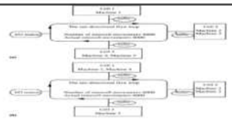
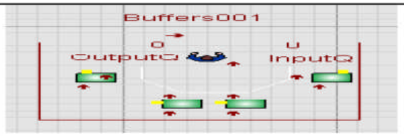
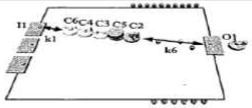
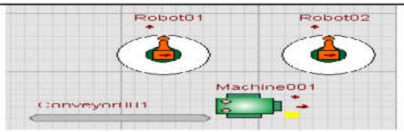
Patchong et al(2003)	 Assembly Line Machines, Conveyors, Buffers, Labour, Robots		Witness components Machine Conveyor Buffer Labour, Robot
Bussmann & Sieverding (2002)	 Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour,
Aase et al (2004)	 Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour,
Freiheit et al (2008)	 Paced Assembly Line Machines, Conveyors, Buffers, Labour, Gantry Cranes		Witness components Machine Conveyor Buffer Labour, Gantry Crane
Article (modern material handling 2004) BMW	 Assembly Line Machines, Conveyors, Buffers, Labour, Gantry Cranes, AGV'S		Witness components Machine Conveyor Buffer Labour, Gantry Crane, AGV & Track
Kekre et al (2003)	 Assembly Line (Visteon) Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour,
Cho et al (1997)	 Assembly Line Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour,

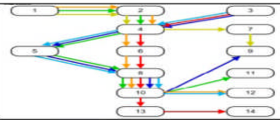
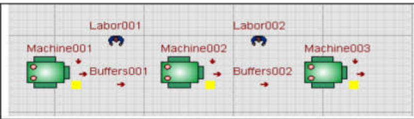
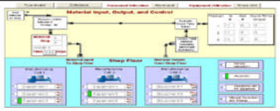
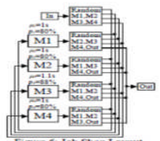
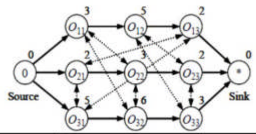
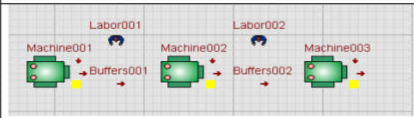
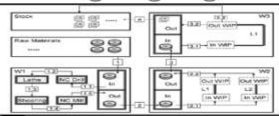
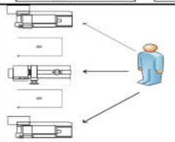
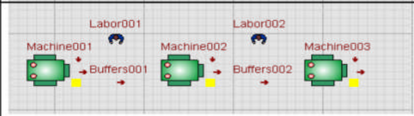
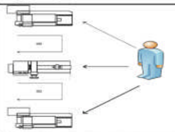
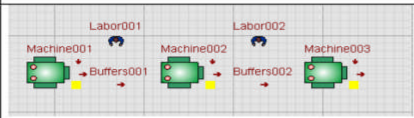
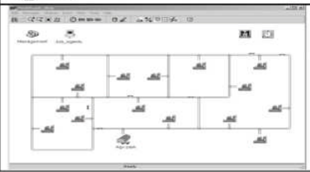
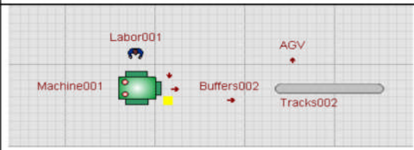
Author	Model taken from Literature review		Witness Model	Witness File
K.Farahmand (2000)		Manufacturing Cell: Machines, Conveyors, Buffers, Labour		MachiningCell.mod
Y.Lee & S.Kim (2000)		Manufacturing Cell: Machines, Conveyors, Input and output Buffers, Labour		MachiningCell.mod
R.Kyle Jr C.Ludka (2000)		Manufacturing Cell: Machines, Conveyors, Buffers, Labour (Furniture Manufacture)		MachiningCell.mod
C.Williams & P.Chompuming (2002)		Robotic Work Cell: Machines, Conveyors, Robots (Metal Fabrication Plant)		Witness Components: Robots Machines Conveyor
F.Cheng (2000)		Robotic Work Cell: Machines, Conveyors, Robots		Witness Components: Robots Machines Conveyor
Roser et al (2001)		Manufacturing Cell: Machines, Buffers, Labour		MachiningCell.mod
R.Chawla & A.Banerjee (2001)		Robotic Work Cell: Machines, Conveyors, Robots		Witness Components: Robots Machines Conveyor

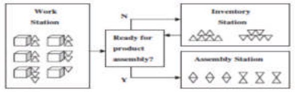
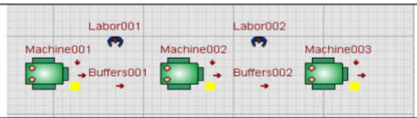
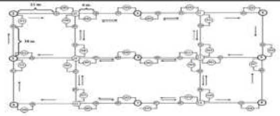
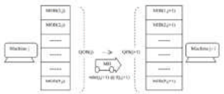
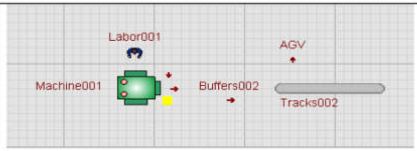
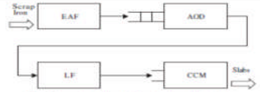
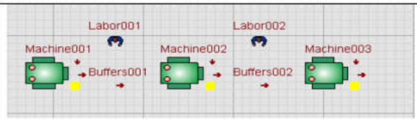
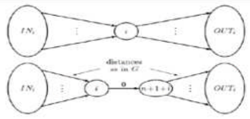
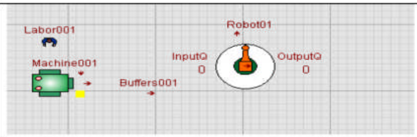
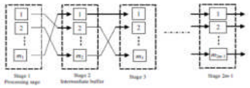
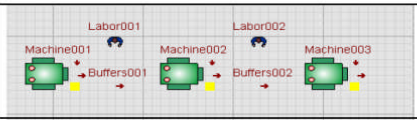
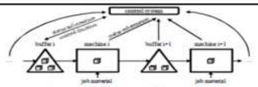
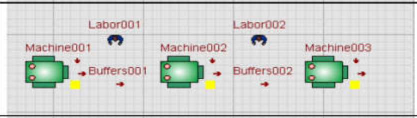
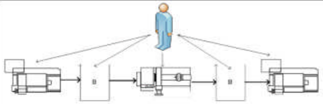
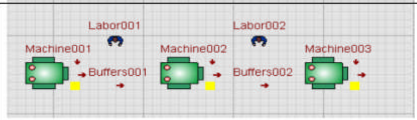
Author	Model taken from Literature review		Witness Model	Witness File
M.Altinkilinc (2004)		Manufacturing Cell: Machines, Manual Buffers, Labour		Standard Work Cell Taken from the Advanced Tab Functions.
S.Gahagan & J. Herrmann (2001)		Manufacturing Cell: Machines, Manual Buffers, Labour & AGV'S		Standard Work Cell + Vehicle or Machinigcell.mod + Vehicle
S.Mass & C.Stanridge (2005)		Manufacturing Cell: Machines, Conveyors & labour		MachiningCell.mod
D.Thapa et al (2008)		Robotic Work Cell: Machines, Conveyors, Robots & Carriers		Witness Components: Robots Machines Conveyor Vehicle
H.Hibino & Y.Fukuda (2008)		Robotic Work Cell: Machines, Conveyors, Robots, Palletizer		Witness Components: Robots Machines Conveyor
C.MacDonald & E.Gunn (2008)		Manufacturing Cell: Machines, Buffers & labour		MachiningCell.mod Or Standard Work Cell + Buffer
Campbell et al (1999)		Manufacturing Cell: Machines, Buffers & labour		MachiningCell.mod Or Standard Work Cell + Buffer

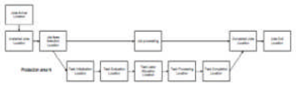
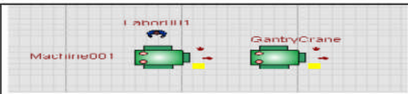
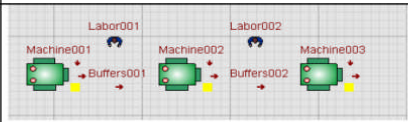
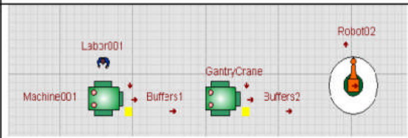
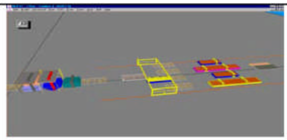
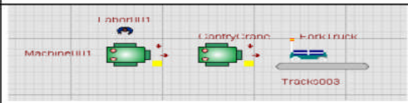
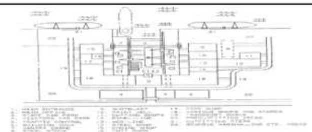
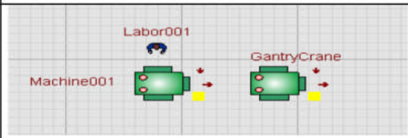
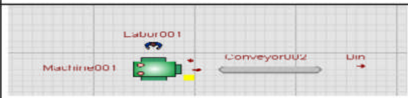
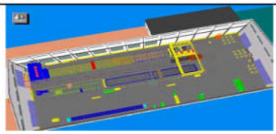
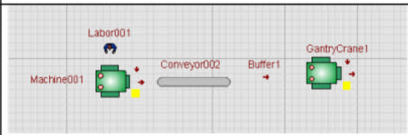
Author	Model taken from Literature review	Witness Model	Witness File
Shady et al (1997)	 Manufacturing Cell: Machines, Buffers, Labour & Gantry Crane		MachiningCell.mod Modified (removal of conveyor + addition of one machine)
E.Eneyo & G.Pannirselvam	 Manufacturing Cell: Machines, Buffers, Labour		Standard Work Cell + Buffer or Machinigcell.mod
S.Hurley & D.Whybark (1999)	 Manufacturing Cell: Machines, Conveyors , Buffers, labour,		MachiningCell.mod
O.Ulgen & S.Upendram	 Robotic Work Cell: Conveyors, Robots & Gantry Crane		Witness Components: Robots Conveyor Gantry Crane
Safaei et al (2008)	 Manufacturing Cell: Machines, Robots, AGV		Witness Components: Robots Machines AGV Possible modeling through advanced tab features + robot & AGV
Vitanov et al (2007)	 Manufacturing Cell: Machines & labour		Standard Work Cell
Askin et al (1997)	 Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Paquet & Lin (2003)	 Manufacturing Cell: Machines, Conveyors , Buffers, labour,		MachiningCell.mod

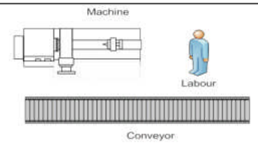
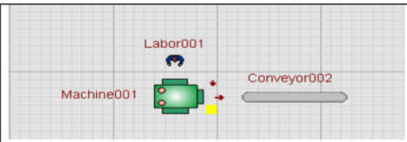
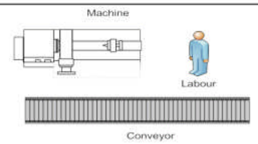
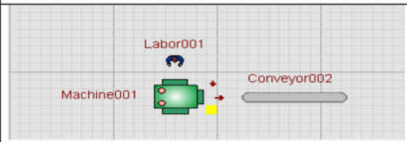
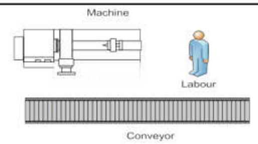
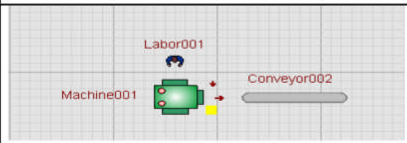
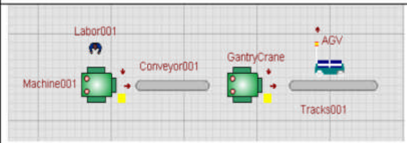
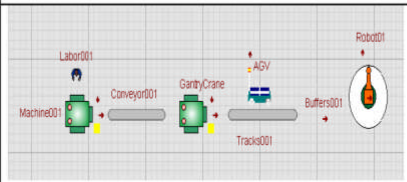
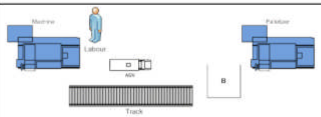
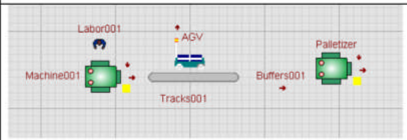
Safaei et al (2008)		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Lari and Kaebernick (1997)		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Zolfaghari & Roa (2005)		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Shambu & Suresh (2000)		Manufacturing Cell: (Move from job shop to cell) Machines, Buffers & labour		Standard Work Cell + Buffer
Cheng (2003)		Robotic Manufacturing Cell: Machines, Conveyor & Robot		Witness Components: Machine Conveyor Robot
Benjaafar (2000)		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Campbell et al (1999)		Manufacturing Cell: Machines, Conveyors, Labour, Transport Vehicle, Interbay monorail system		Witness components Machine, Labour, Conveyor, vehicle, Track system
Chen et al		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer

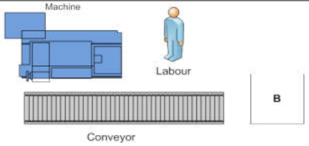
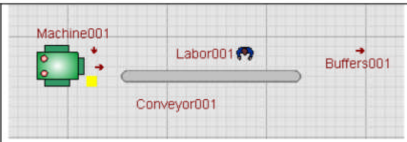
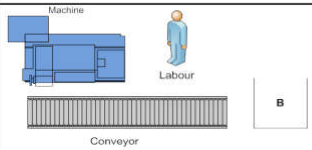
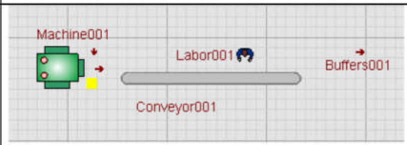
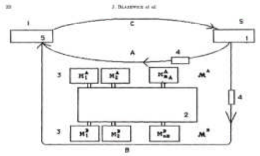
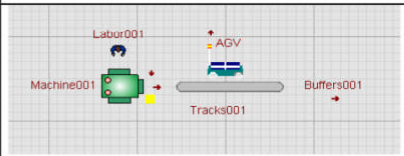
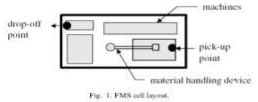
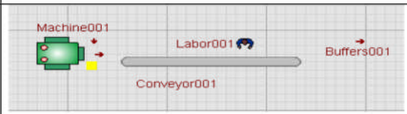
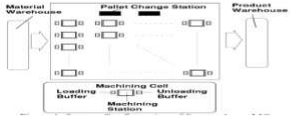
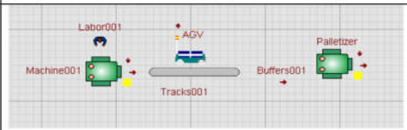
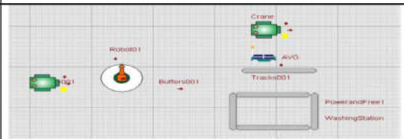
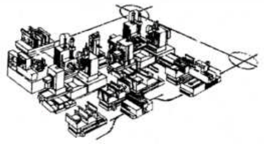
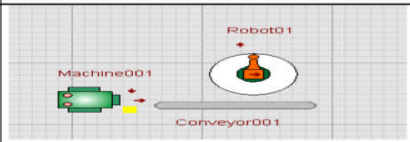
Irani and Huang (2000)		Manufacturing Cell: Machines, Buffers & labour		Standard Work Cell + Buffer
Luong et al (2002)		Manufacturing Cell: Machines, Conveyors Buffers & labour		MachineCell.mod
Adil Baykasolu (2003)		Manufacturing Cell: Machines, Manual Buffers & labour		Standard Work Cell + Buffer
Saad et al (2002)		Manufacturing Cell: Machines, Conveyors Buffers & labour		MachineCell.mod
Lee & Chiang (2002)		Manufacturing Cell: Machines, Manual Buffers & labour		Standard Work Cell + Buffer
Yamada (2002)		Robotic Manufacturing Cell: Machines, Conveyors , Robots		Witness Components: Machine Conveyor Robot

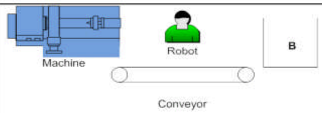
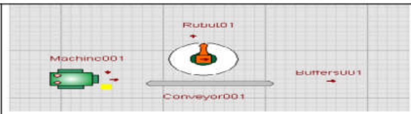
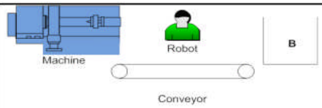
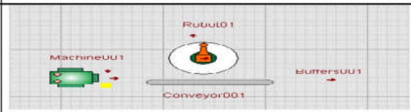
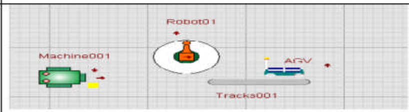
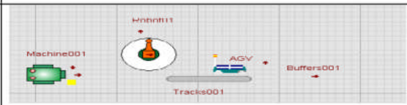
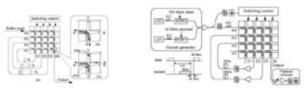
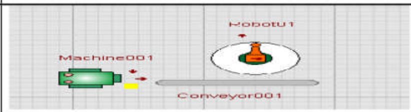
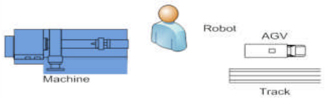
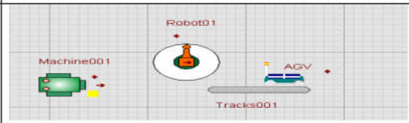
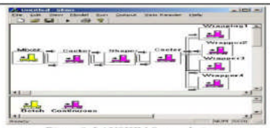
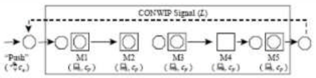
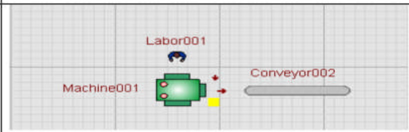
Kirchhof etal (2008)		Job Shop: Machines, Labour, Manual Buffers (Bins), Manual Transport (Carts)		Witness components Machine Labour, Buffer
Kress et al (2006)		Job Shop: Machines, Labour, Manual Buffers (Bins),		Witness components Machine Labour, Buffer
Roser et al (2002)	 Figure 6: Job Shop Layout	Job Shop: Machines, Labour, Manual Buffers (Bins),		Witness components Machine Labour, Buffer
Chong et al (2006)		Job Shop: Machines, Labour, Manual Buffers		Witness components Machine Labour, Buffer
Huang et al (2008)		Job Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
J.Li (2003)		Job Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Moon & Lee (2000)		Job Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Lengyel et al (2003)		Job Shop: Machines, Labour, Buffers, AGV'S		

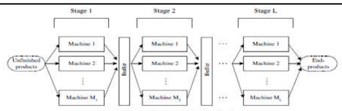
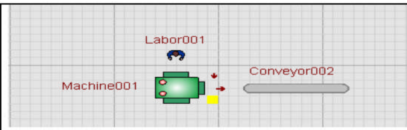
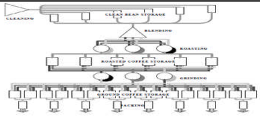
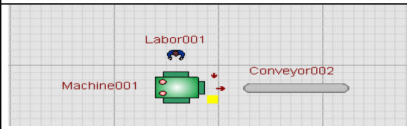
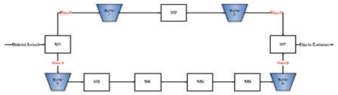
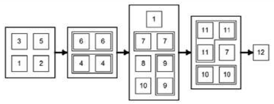
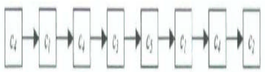
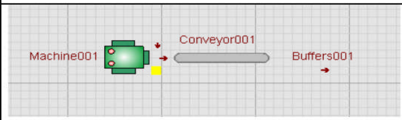
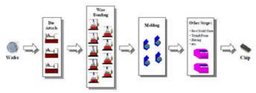
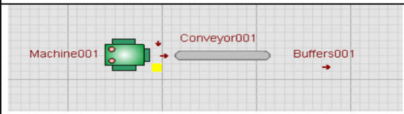
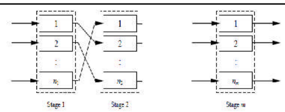
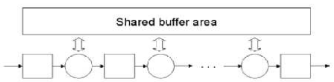
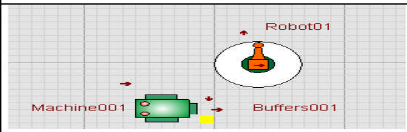
Author	Model Taken from Literature		Witness Model	Witness Components
Chan et al (2006)		Job Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Kesen & Baykoc (2007)		Job Shop: Machines, Labour, Buffers, AGV'S		Witness components Machine Labour, Buffer AGV
Prasad et al (2006)		Flow Shop: Machines, Labour, Buffers, Vehicle (Transport system)		Witness components Machine Labour, Buffer AGV
M.Pranzo (2003)	 Fig. 1. Layout of the stainless steel production line.	Flow Shop: (Parallel Machines) Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Brauner et al (2003)		Flow Shop: Machines, Labour, Buffers, Robots		Witness components Machine Buffer Labour Robot
Akrami et al (2006)		Flow Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Aufenanger et al (2008)	 Figure 2: Flow-Shop decision scheme	Flow Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer
Wang (2000)		Flow Shop: Machines, Labour, Buffers		Witness components Machine Labour, Buffer

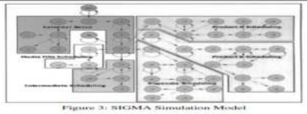
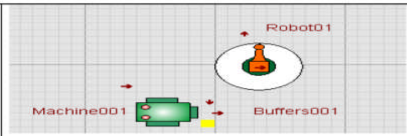
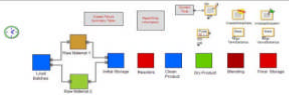
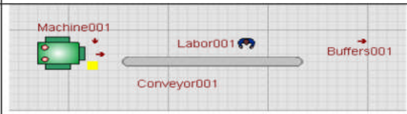
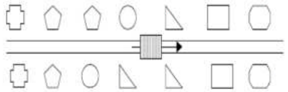
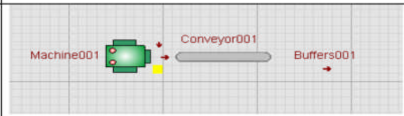
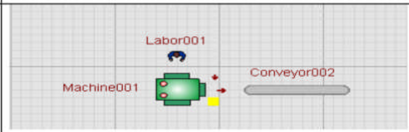
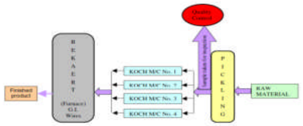
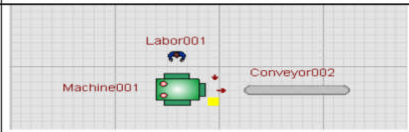
McLean & Shao (2001)		Fixed Position layout: Machines, Labour, Crane		Witness components Machine Labour,
Huang et al (2006)		Fixed Position layout: Machines, Labour, Buffer, Manual Trolley		Witness components Machine Labour, Buffer
Jasnau et al (2002)		Fixed Position layout: Machines, Labour, Buffer, Gantry Crane, Robots		Witness components Machine Labour, Buffer Robot
Medeiros et al (2000)		Fixed Position layout: Machines, Labour, Crane		Witness components Machine Labour,
Burnett et al (2008)		Fixed Position layout: Machines, Labour, Overhead Cranes, Fork Trucks		Witness components Machine Labour, Vehicle & Track
Hamid CHABANE (2004)		Fixed Position layout: Machines, Labour, Crane		Witness components Machine Labour,
Gujarathi et al(2004)		Transfer Line: Machines, Conveyor Labour, Manual Buffer (Bins)		Witness components Machine Labour, Buffer Conveyor
Williams et al (2001)		Transfer Line: Machines, Conveyor Labour, Buffer, Gantry Crane		Witness components Machine Labour, Buffer Conveyor

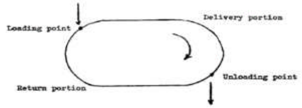
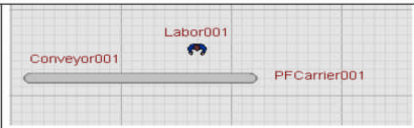
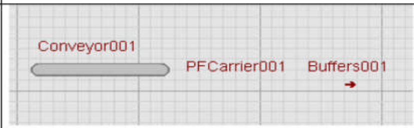
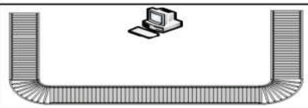
Ladbrook & Januszczak (2001)		Transfer Line: Machines, Conveyor Labour,		Witness components Machine Labour, Conveyor
Dolgui et al (2008)		Transfer Line: Machines, Conveyor Labour,		Witness components Machine Labour, Conveyor
Ladbrrok &Januszczak (2001)		Transfer Line: Machines, Conveyor Labour,		Witness components Machine Labour, Conveyor
Roberto Michel (2004)		Transfer Line: Machines, Conveyor Labour, AGV'S, Cranes		Witness components Machine Labour, Conveyor AGV & Track
Patrick Waurzyniak (2003)	Cylinder heads for Ford's 3-valve 5.4-liter V-8 move along palletized conveyors to the Cross Hüller flexible CNC machining cells at the Windsor Engine Plant. 	FMS: Machines, Conveyor Labour, AGV'S, Cranes Robots, Buffers		Witness components Machine Labour, Conveyor AGV & Track Buffer Robot
Dario Pacciarelli (2001)		FMS: Machines, Buffers, Labour, Rail guided vehicles, Palletizer		Witness components Machine Labour, AGV & Track Buffer

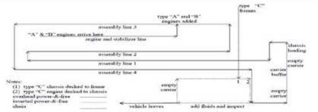
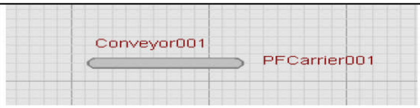
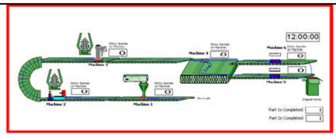
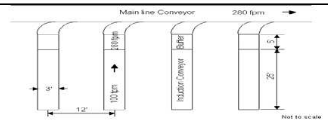
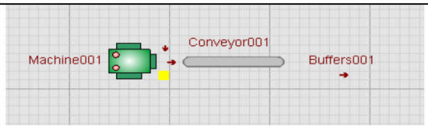
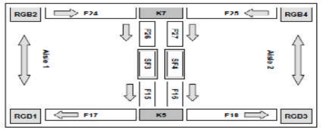
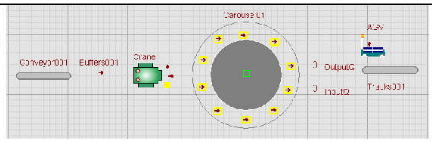
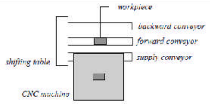
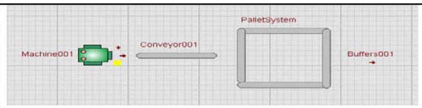
Caprihan & Wadhwa (2004)		FMS: Machines, Conveyor Buffers, Labour,		Witness components Machine Conveyor Labour, Buffer
Potts & Whitehead (2001)		FMS: Machines, Conveyor Buffers, Labour,		Witness components Machine Conveyor Labour, Buffer
Blazewicz et al		FMS: Machines, Buffers, Labour, AGV		Witness components Machine Labour, Buffer AGV Track
Yang et al (2005)		FMS: Machines, Conveyor Buffers, Labour,		Witness components Machine Conveyor Labour, Buffer
Fujii et al (2000)		FMS: Machines, Buffers, Labour, Rail guided vehicles, Palletizer		Witness components Machine Labour, AGV & Track Buffer
S.Takakuwa (1997)		FMS: Machines, Buffers, Rail guided vehicles, Palletizer, Robots, Cranes,		Witness components Machine Robot AGV & Track Buffer Palletizer, Crane
Koren et al (1997)		RMS: Machines, Conveyors, Robots		Witness components Machine Conveyor Assembly Robots

Korhonen et al (2001)		RMS: Machines, Conveyors, Robots, Buffers		Witness components Machine Conveyor Robots Buffer
Johansson & Williams et al (2004)		RMS: Machines, Conveyors, Robots, Buffers		Witness components Machine Conveyor Robots Buffer
Abdi & Labib (2003)		RMS: Machines, Robots, AGV		Witness components Machine Robots AGV Tracks
Reiter & Freitag (2007)		RMS: Machines, Robots, AGV, Buffer		Witness components Machine Robots AGV Tracks Buffer
Wang et al (2003)		RMS: Machines, Conveyors, Robots		Witness components Machine Conveyor Assembly Robots
Meng et al (2004)		RMS: Machines, Robots, AGV		Witness components Machine Robots AGV Tracks
Chen & Pidd (2005)	 Figure 2: LANSKIM Screenshot	Quasi Continuous manufacturing System Machines, Conveyors, Buffer, Labour		Witness components Machine Conveyor Labour, Buffer
Enns & Rogers (2008)	 Figure 1: Flowline Configuration	Flexible Flowline Machines, Conveyors, Labour		Witness components Machine Labour, Conveyor

Quadt & Kuhn (2006)	 Fig. 1. Schematic view of a flexible flow line.	Flexible Flowline Machines, Conveyors, Labour		Witness components Machine Labour, Conveyor
Vaidyanathan et al (1998)		Flexible Flowline Machines, Conveyors, Labour		Witness components Machine Labour, Conveyor
Athapornmongkon et al (2006)	 Figure 3: Parallel Production Flow	Flexible Flowline Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Irani & Huang (2006)		Flexible Flowline Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Sodhi & sarker (2003)		Flexible Flowline Machines, Conveyors, Buffers		Witness components Machine Conveyor Buffer
Quadt & Kuhn (2003)		Flexible Flowline Machines, Conveyors, Buffers		A single-stage, multi-product capacitated parallel machine Witness components Machine Conveyor Buffer
Moghaddam et al (2005)		Flexible Flowline Machines, Conveyors, Buffers, Labour		Witness components Machine Conveyor Labour, Buffer
Matta et al (2005)	 Fig. 2. Scheme of the proposed system architecture	Flexible Flowline Machine, Buffers, Robots		Witness components Machine Buffer Robot

P.Saraph (2002)		Product Layout Machine, Buffers, Robots		Witness components Machine Buffer Robot
Sharda & Bury (2008)		Product Layout Machine, Buffers, Conveyors, Labour		Witness components Machine Conveyor Labour, Buffer
Benjafaar et al (2000)		Product Layout Machine, Buffers, Conveyors		Witness components Machine Conveyor Buffer
Nembhard et al (1999)		Product Layout Machine, Conveyors, Labour		Witness components Machine Labour, Conveyor
Thomas et al (2002)		Product Layout Machine, Conveyors, Labour		Witness components Machine Labour, Conveyor

T. T. Kwo (General Electric)		Conveying Network Conveyors, Carriers, Labour		Witness components Conveyor Labor Carrier
MOLLY V. STRZELECKI (2007)		Conveying Network Conveyors, Buffers, Carriers		Witness components Conveyor Buffer Carrier
Controleng (2000)		Conveying Network Conveyors, Carriers, Pc driven		Witness components Conveyor Carrier

Williams and Celik (1998)		Conveying Network Conveyors, Carriers,		Witness components Conveyor Carrier
Tavakoli et al (2008)		Conveying Network Machine, Buffers, Conveyors, Labour		Witness components Machine Conveyor Labour, Buffer
Jing et al (1998)		Conveying Network Machine, Buffers, Conveyors		Witness components Machine Conveyor Buffer
K. Weigl (1998)		Conveying Network Conveyors, Buffers, Cranes, Elevators, Rail Guided Vehicle		Witness components Machine Conveyor Buffer Power and free conveyor or Carousel AGV & Track
Bussmann & Schild (2001)		Conveying Network Machines Conveyors, Buffers, Pallets,		Witness components Machine Conveyor Buffer Power and free conveyor or Carousel

APPENDIX 2: THE VARIOUS MODELLING SCENARIOS

RapidSim Modelling Scenarios:

The most important concept of the RapidSim modelling approach is the use of pre-built ready to use templates which can be used on their own or in combination with other templates to quickly design, assemble and run a simulation model. In the RapidSim approach the components are all combined to form a single module which contains all the part routing, the inputs and outputs and the necessary logic for making the model work. One of the most important aspects to this approach is the repeatability it offers. Modules can be used and reused within any simulation model thereby eliminating the need for continuous design or redesign. As modules are made up of various combinations of simulation components (machine, buffer, conveyor etc.) building a model is as easy as selecting the modules which represent the components used in the system and simply assembling these modules in a pre-developed template to form the completed model

The versatility of the RapidSim interface is brought to light when the interface is used as a means of building new and existing layouts. The following are some of the various scenarios under which the RapidSim software can be utilized to aid the simulation model building process.

Scenario 1

In this scenario the user is given the task of designing a layout using the RapidSim approach. The layout is based on a simple “U” shaped design and it is comprised of both single and combined components. The single components that make up the model are machines, buffers and conveyors. The list of combined elements incldes machines + labor, machines + buffers, machines + conveyors and machines + buffers + conveyors + labor. All flow through the system is sequential and the machine utilization of the fourth machine is to be measured. The work in progress as well as the time the part spends in the model also needs to be measured. Figure 47 below shows the model created using the RapidSim interface. The position of the components is depicted in the component position window and dictates the final shape of the layout. The replicated layout is shown in figure 48 and it matches the layout depicted in the component position window of the interface.

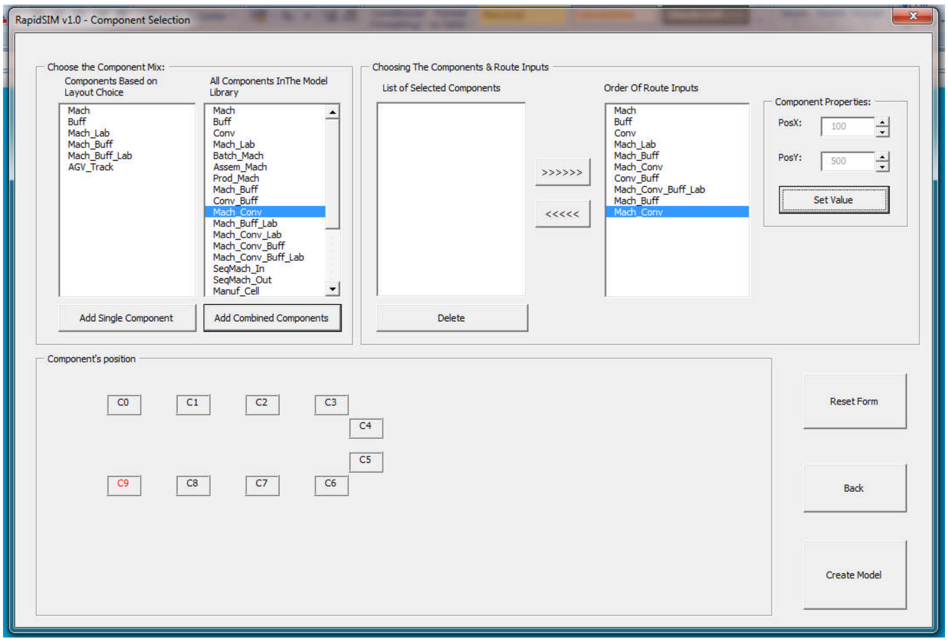


Figure 47: The RapidSim "U" shaped model

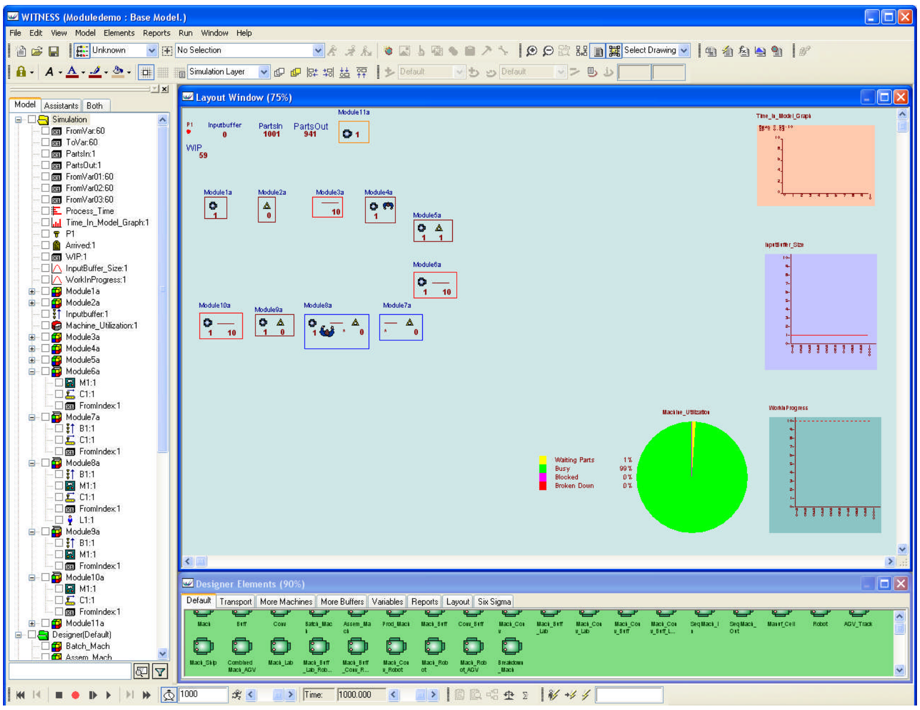


Figure 48: The generated "U" shaped model

Scenario 2

In this scenario the user is given the task of designing a layout using the RapidSim approach. The layout is based on an "S" shaped design and is comprised of both single and combined components. The single components that make up the model are machines, buffers and conveyors. The list of combined elements incldes machines + labor, machines + buffers, machines + conveyors, conveyors + buffers, machines + buffers + labor, machines + conveyors + buffers and machines + buffers + conveyors + labor. All flow through the system is sequential and the machine utilization of the fourth machine , located in module 7 is to be measured. The work in progress as well as the time the part spends in the model will also be measured. Figure 49 below shows the model created using the RapidSim interface. The position of the components is depicted in the component position window and dictates the final shape of the layout. The replicated layout is shown in figure 50 and it matches the layout depicted in the component position window of the interface.

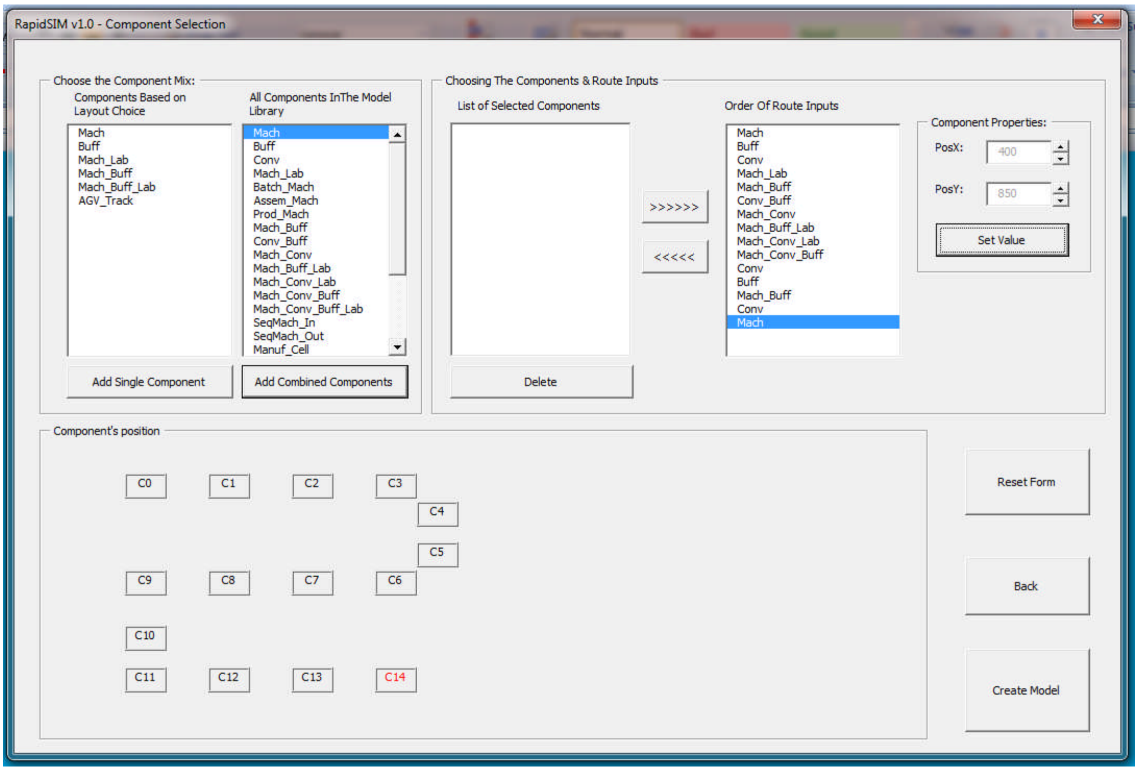


Figure 49: The RapidSim "S" shaped model

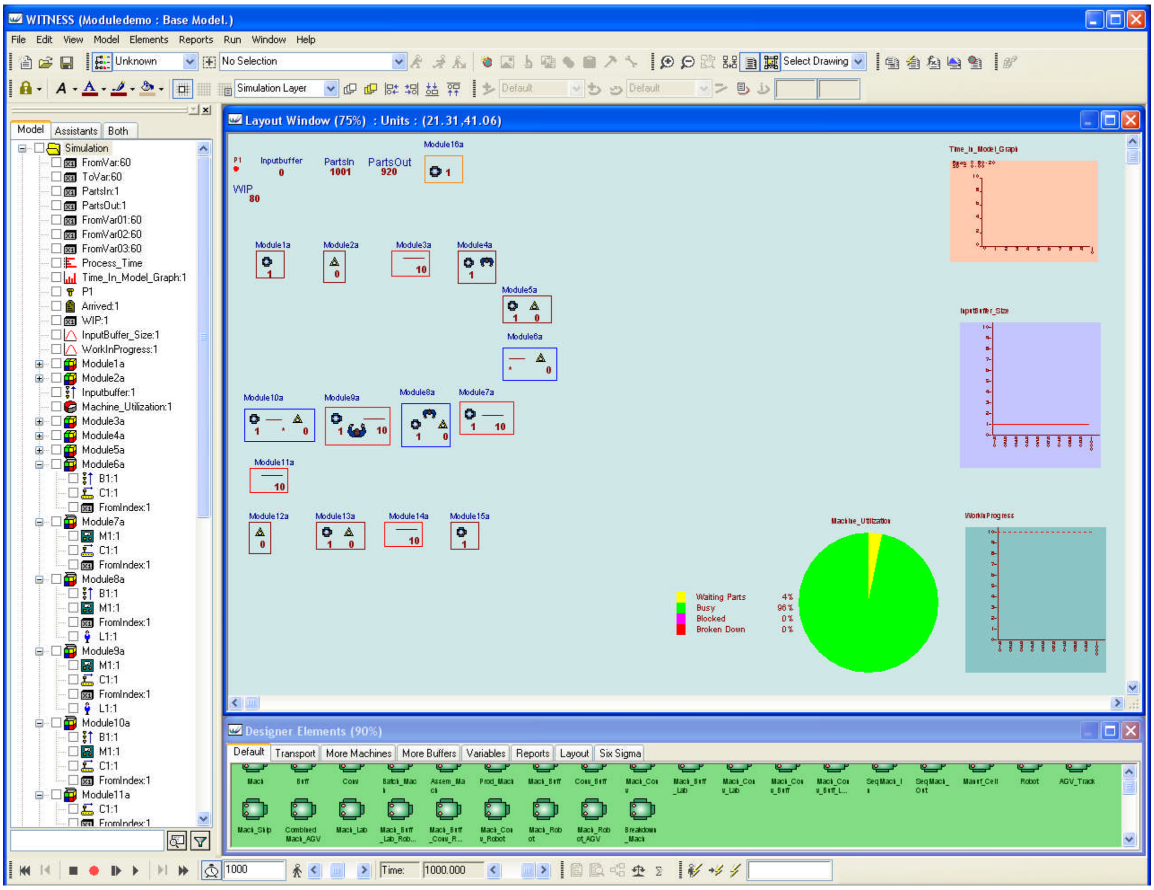


Figure 50: The generated "S" shaped model

Scenario 3

In this scenario the user is given the task of designing a layout based on the design shape given and is comprised of both single and combined components. The single components that make up the model are machines, buffers and conveyors. The list of combined elements incldes machines + labor, machines + buffers, conveyors + buffers, and a sequence out machine. In this scenario all flow through the system is not sequential. Sequential flow takes place for the first 5 modules then it is split into two diverging arms which are both fed by module 5. The sequence command is used to regulate the flow of parts to modules 6 and 7 and it is also used to recombine the processed parts from both these flowstreams into module 8. The machine utilization of the fourth machine , located in module 7 is to be measured. The work in progress as well as the time the part spends in the model will also be measured. Figure 51 below shows the model created using the RapidSim interface and the replicated layout is shown in figure 52.

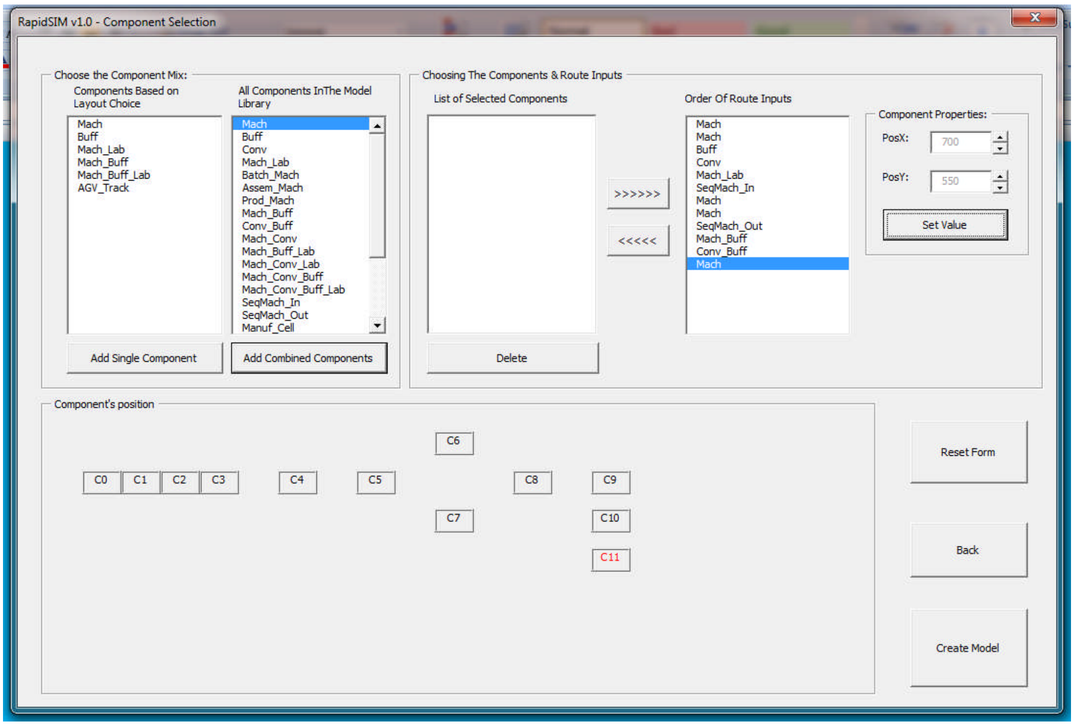


Figure 51: The RapidSim "sequence" model

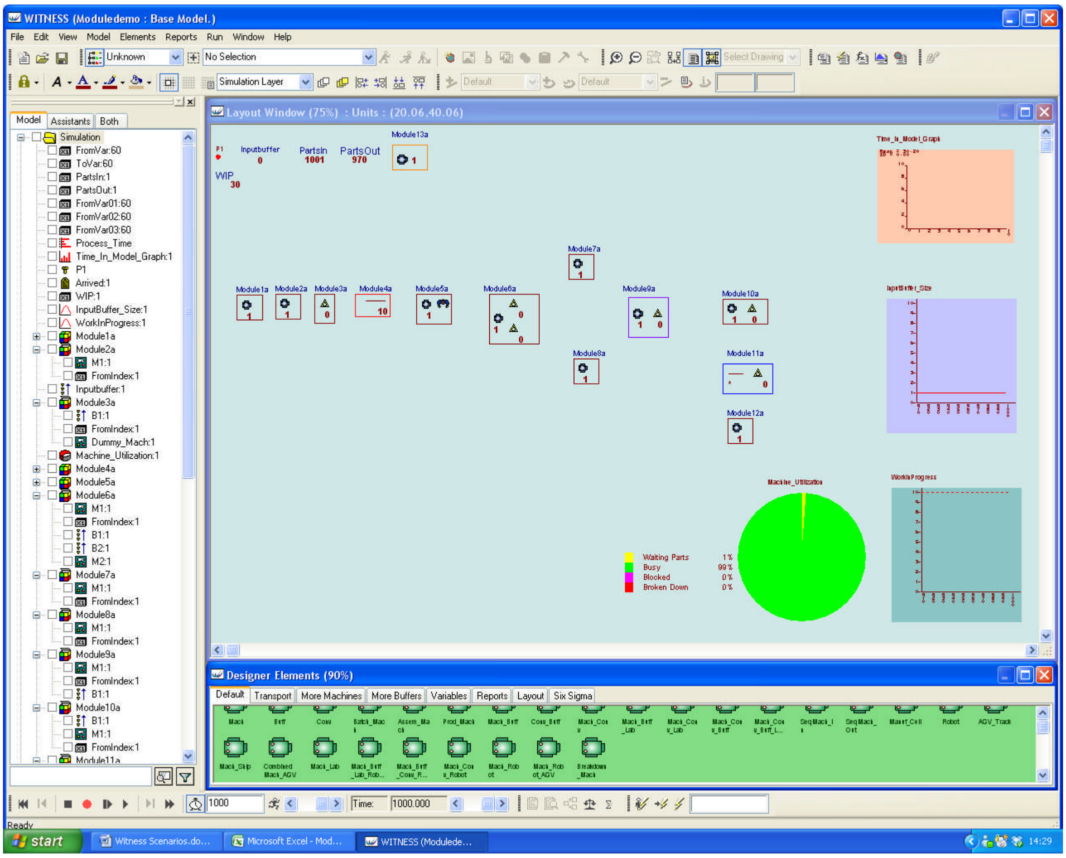


Figure 52: The generated "sequence" model

Scenario 4

In this scenario the user is given the task of designing a layout based on the design shape given and is comprised of both single and combined components. The single components that make up the model are machines, buffers and conveyors. The list of combined elements incldes machines + labor, robots and a completed manufacturing cell. In this scenario all flow through the system is not sequential and the elements of robots as well as fully functional manufacturing cells are introduced. A robot is used to transfer the part into the manufacturing cell in module 5 and it utilises the percentage command as part of its output logic structure. The robot is also used to transfer parts directly onto the conveyor located in module 6. The conveyor located in module 6 is fed by both the robot and the manufacturing cell. The same principle of operation is used to dictate the work done in modules 8 and 9. In this scenario the maufacturing cell can act as a mainline processing station or it can be utilised as an out of line repair station, depending on the end user requirements. The machine utilization of the fourth machine , located in module 7 is to be measured. The work in progress as well as the time the part spends in the model will also be measured. Figure 53 below shows the model created using the RapidSim interface and the replicated layout is shown in figure 54.

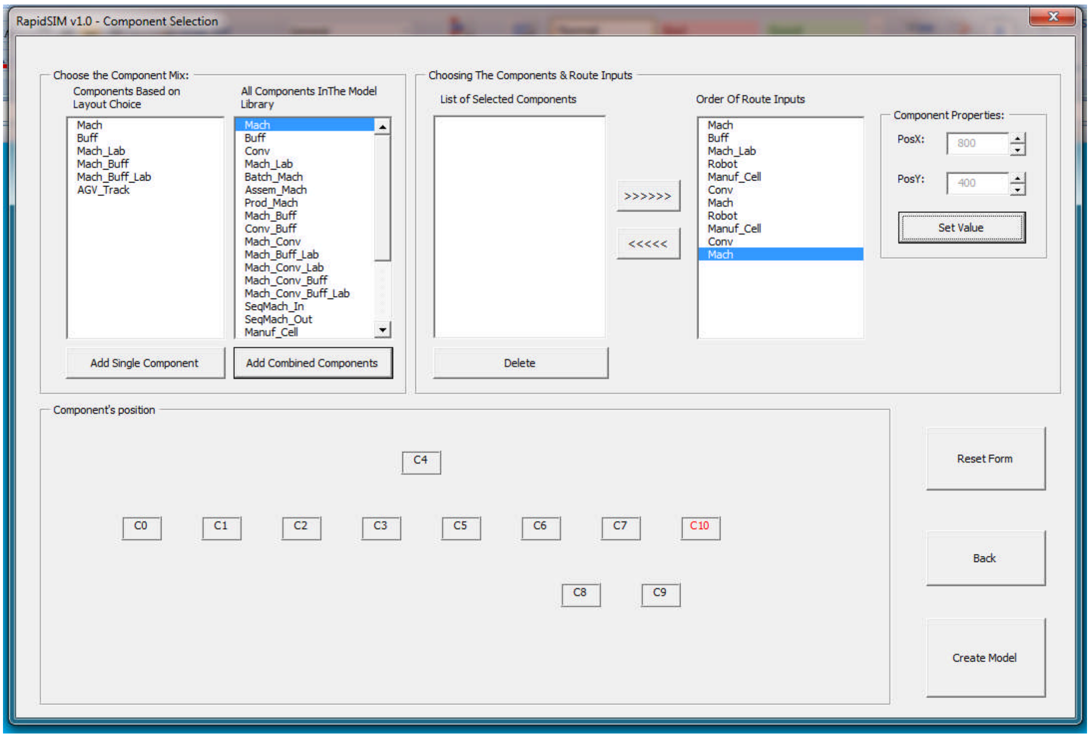


Figure 53: The RapidSim “machining cell” model

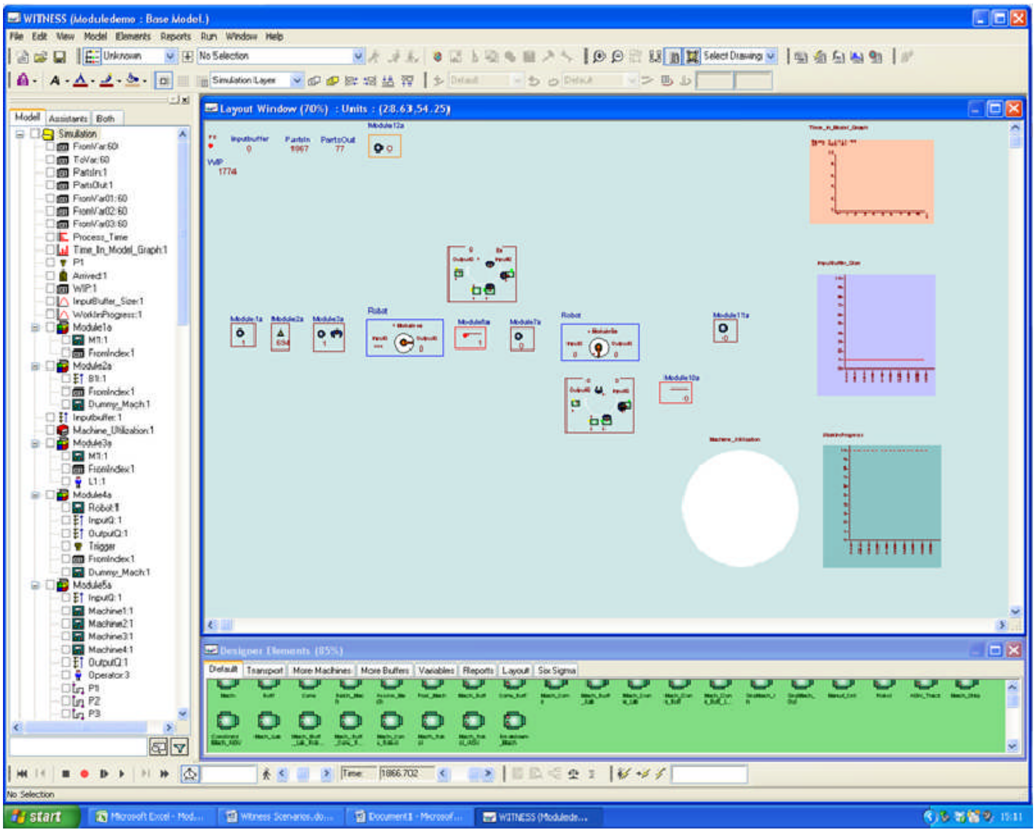


Figure 54: The generated "machining cell" model

Scenario 5

In this scenario the user is given the task of designing a layout based on the design shape given and is comprised of both single and combined components. The main reason behind this model scenario is to demonstrate the range of both complex systems and componets which can be utilized in the RapidSim approach to model building. The single components that make up the model are machines and conveyors. The list of combined elements incldes machines + buffers, AGV's and tracks and a combined component made up of mach + buff + labour + conveyor + AGV + Track. In this model the elements of AGV's are introduced into the model building process . The AGV modules are made up of both the AGV and the tracks as one completed element. The combined AGV module is made up of two modules which are then combined to form one functional element. Work flows through the system and transportation of the parts are handled by both AGV's and conveyors.Parts are fed into the AGV + track system via module 3. The part is then transported via the AGV to the machine located in module 5 where it is worked on. The part is then pushed onto module 6 where further processing takes place as well as transportation to the next station in module 7. The machine utilization of the fourth machine , located in module 6 is to be measured. The work in progress as well as the time the part spends in the model will also be measured. Figure 55 below shows the model created using the RapidSim interface and the replicated layout is shown in figure 56 .

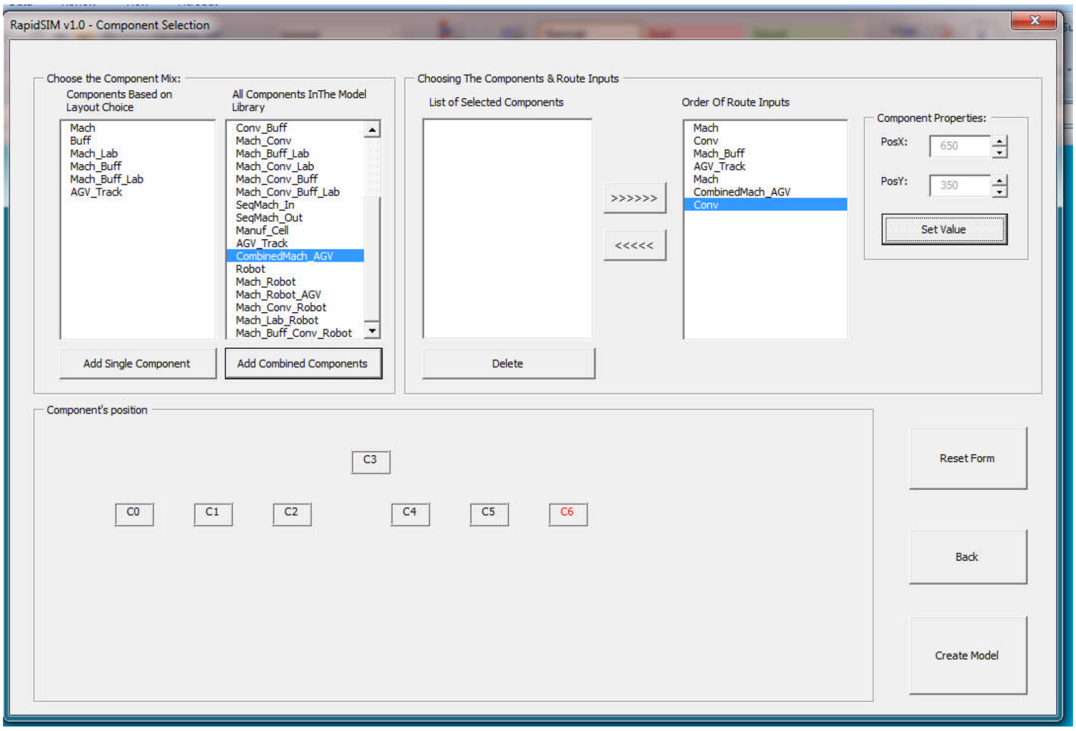


Figure 55: The RapidSim “AGV” model

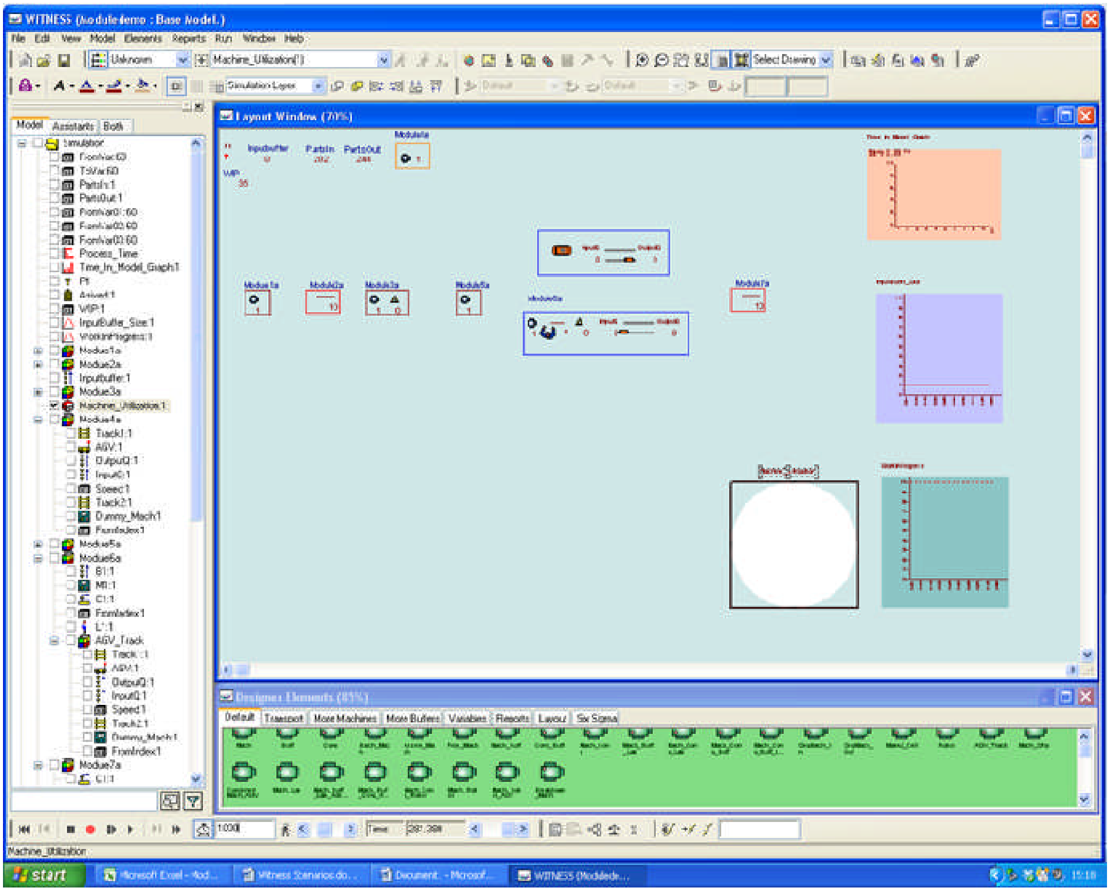


Figure 56: The generated "AGV" model

Scenario 6

In this final scenario the user is given the task of designing a layout based on the design shape given. The main purpose of designing and building this layout is to demonstrate how large complex models can be built using the RapidSim approach. The single components that make up the model are machines and conveyors while the list of combined elements incldes conveyors + buffers, machines + conveyors + buffer + labor, combined machine + AGV, machines + conveyors + buffer + Robots and machines + robots + AGV's.

In this model the elements of AGV's, robots and combined modules are introduced into the model building process . The AGV modules are made up of both the AGV and tracks as one completed element, whilst the robot elements are integrated into both the combined compoonennts and the AGV and track systems. Parts are processed in a sequential manner to demonstrate how these complex modules can be easily interconnected whilst mainting their high levels of individual complexity. In module 5 parts are processed via the combined componet element of the module and then transferred onto the AGV and track system for transportation to the next workstation. In module 6 parts are pulled into the module via the machine and then transferred into the storage buffer. A robot then loads and unloads the part into the next procesing station. The parts are then pulled into module 7 via a machine and then transferred via a robot onto the awaiting AGV and track system.

The machine utilization of the fourth machine , located in module 6 is to be measured. The work in progress as well as the time the part spends in the model will also be measured. Figure 57 below shows the model created using the RapidSim interface and the replicated layout is shown in figure 58.

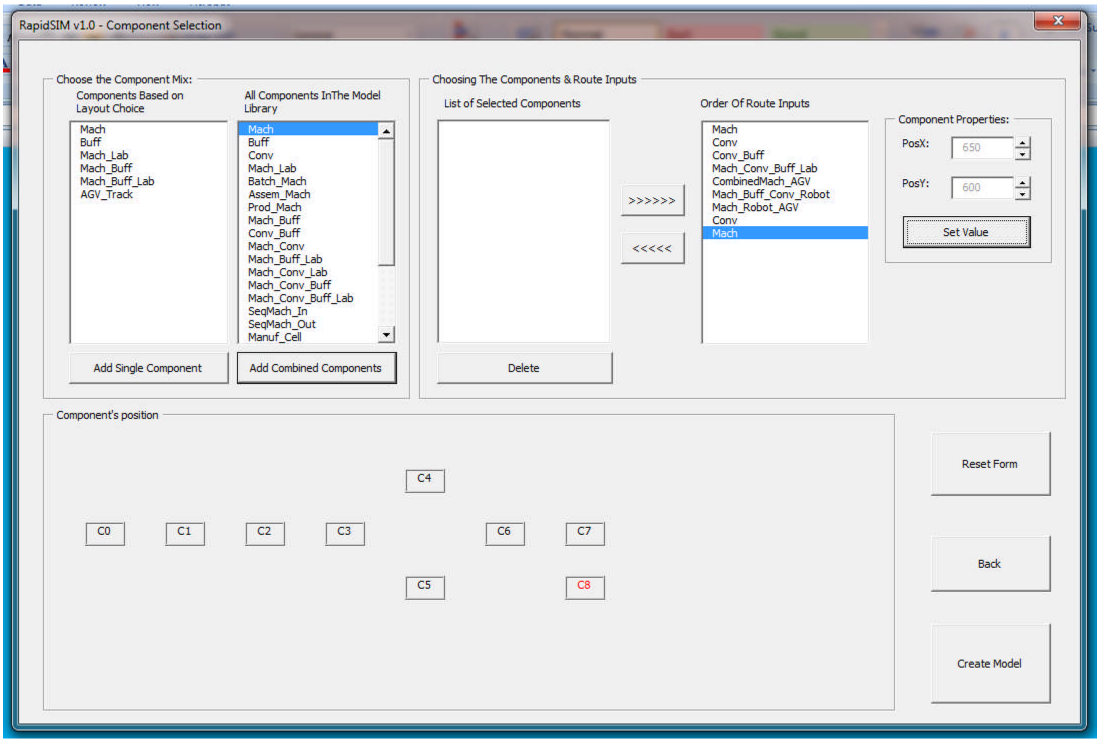


Figure 57: The RapidSim “Complex” model

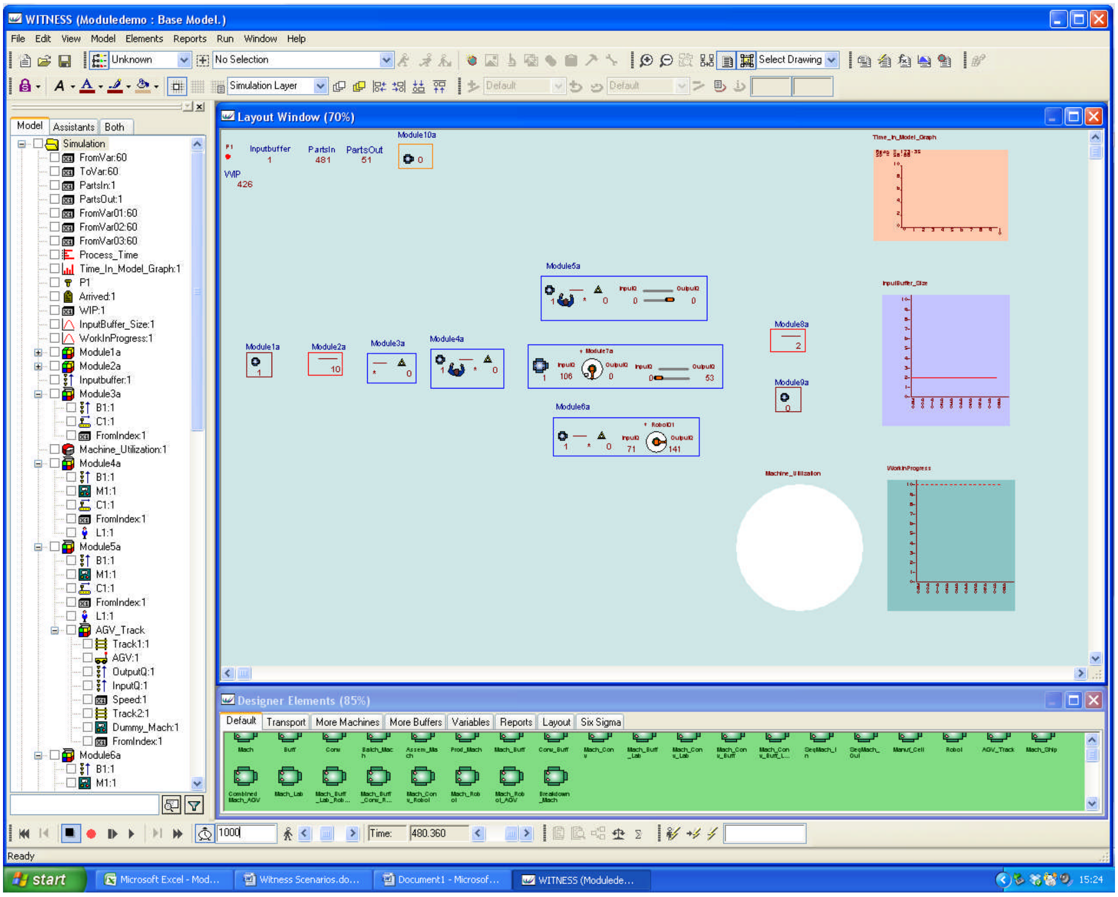


Figure 58: The generated "Complex" model

The various scenarios presented above are all designed with the aim of demonstrating both the flexibility and versatility of the RapidSim interface. Using the interface allows for quick and easy model building whilst at the same time maintaining the high levels of complexity which may be needed in some if not all simulation models.

APPENDIX 3: THE RAPIDSIM USER MANUAL

This section presents the User Manual that has been developed in regard to the prototype rapid model generator (RapidSim).

Abstract

This user manual has been developed by the Rapid Simulation Modelling project at Cranfield University and it provides general information to users regarding the context and guidelines for use of the rapid modelling tool RapidSim. This tool has been developed as a direct response to the challenges faced by simulation modellers when attempting to develop a rapid simulation model. The main focus of the tool has been in reflecting the influence which template based modelling and template based libraries can have on the overall simulation modelling process. Some of the key features of the rapid modelling tool include rapid model development, generic module creation, rapid and easy model manipulation, simplified data collection and improved ease of use.

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Glossary of Terms

RapidSim	Rapid model generation tool
WIP	Work in progress
NPARTS	Number of parts
VBS	Visual basic scripting

Modelling With RapidSim:

About The Interface .

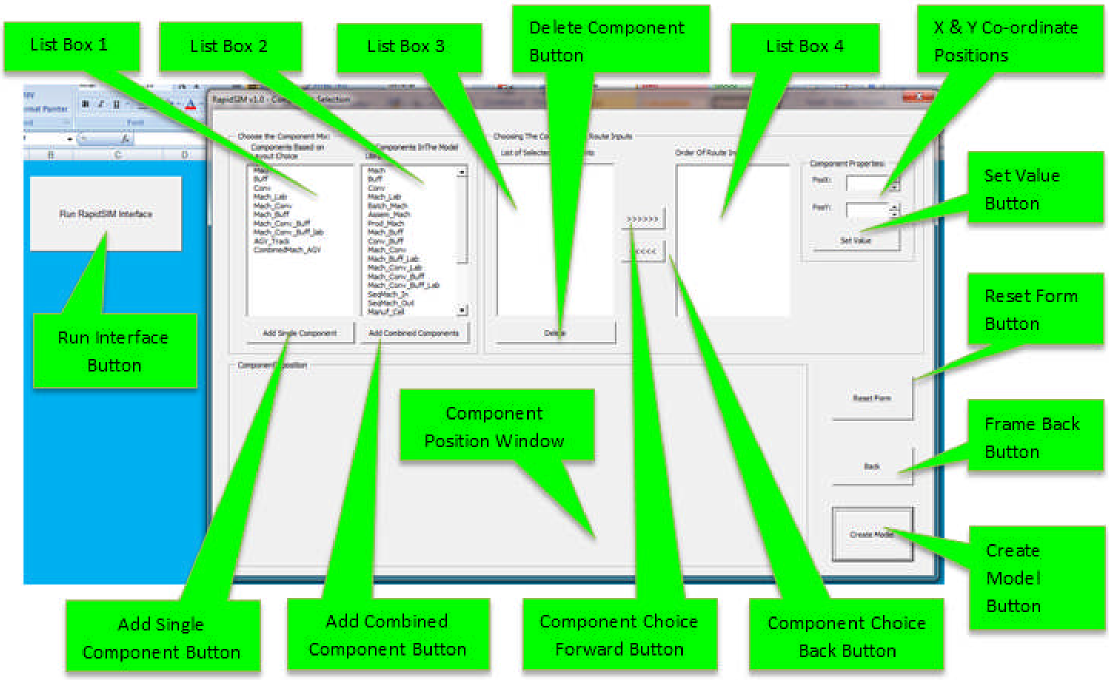


Figure 59: The main interface window

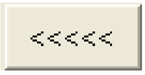
The following information relates to the various aspects of the interface design and their usage as depicted in figure 59 above.

List Box 1 (Components based on layout choice): This list box displays the pre-loaded modules which best represent your choice in steps 1 to 3. These components can be added to the model by highlighting them one at a time and then clicking on the "Add Single Component" button. Any component can be added more than once by highlighting that component and clicking on the "Add Single Component" button repeatedly. The added component/components will be displayed in list box 3.

List Box 2 (All components in the model library): This list box displays all the modules which can be used in the model building process. These components can be added to the model by highlighting them one at a time and then clicking on the "Add Combined Component" button. Any component can be added more than once by highlighting that component and clicking on the “Add Single Component” button repeatedly. The added component/components will be displayed in list box 3.

List Box 3 (List of selected components): This box displays the choice of modules selected from list box 1 and 2. These components are displayed randomly and components can be deleted from the list by highlighting the chosen component and then clicking on the “Delete” button.

Forward Button: This button is used to select your choice of route inputs for the part. Selecting the component and then clicking on the forward button moves the selection into list box 4, which details the order of route inputs according to the order of the components selected.



Back Button: This button is used to de-select components from the order of route inputs which have been placed in list box 4. Selecting the component and clicking on the back button removes the component from order of route inputs and places it back into list box 3.

List box 4 (Order of route inputs): This list box displays the chosen components and the order of their inputs for the simulation model. Components can be added and removed from this field by using the forward and back buttons respectively.

Set Value Button: After the order of route inputs have been decided the set value button is used to set the display position of the component on the Witness screen when the model is created.

Component Position Window: This window displays the co-ordinate positions which have been set for the component using the set value button. This window allows the user to position the icon wherever they choose. The position of the icon in this window depicts the position the icon will appear when it is replicated onto the Witness screen.

Reset Form Button: This button is used to reset all user selections in the interface.

The Back Button: Clicking on this button takes you back to the volume selection window to restart the model building process.

<u>Using RapidSim</u>

In order to use the RapidSim Interface you need to open the corresponding Excel File, which in this case is the “ModuleDemo.xlsm”. This can be found on the desktop in the folder named “Interface Docs”.

Double click on the “ModuleDemo.xlsm” excel file to open it. When opened click on the options button. In the pop up window that opens, select enable this content and then click on OK as shown in figure 60 below, to proceed.

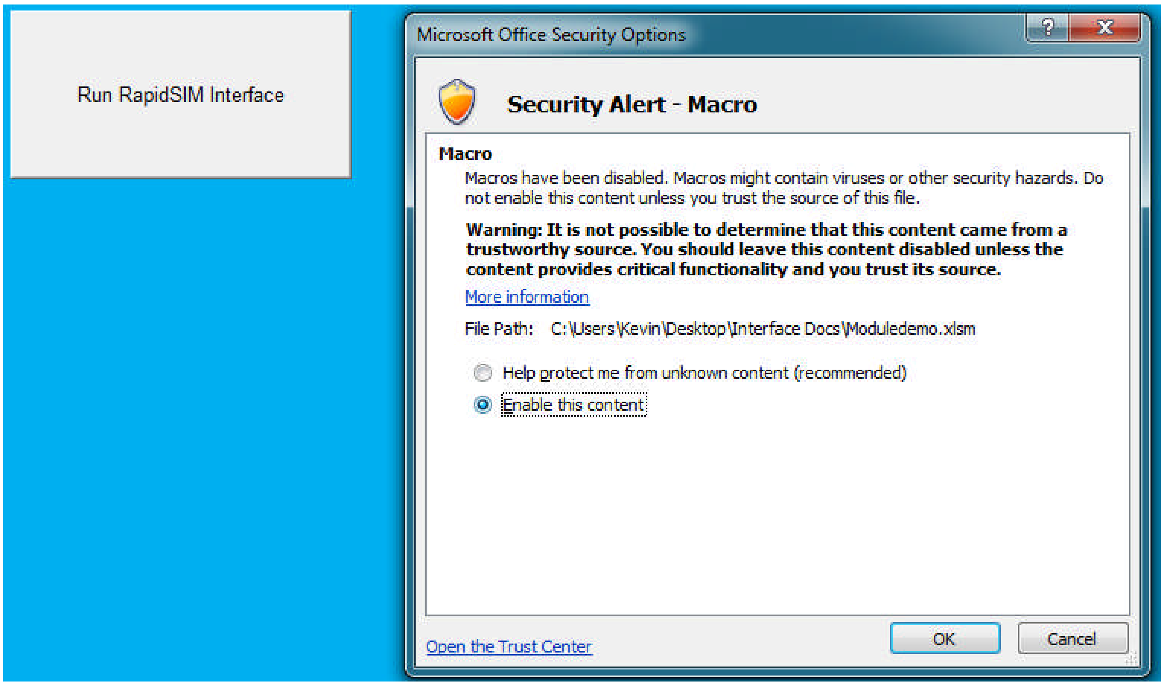


Figure 60: Enabling the system macros

Clicking on OK enables the macros’s which are programmened in this workbook and it imparts full functionality to the interface. Macros are used in the interface to eliminate the need for performing repetitive tasks. This functionality proves useful in helping to decrease the overall model building time.

Click on the Run RapidSim Interface button. A new pop up window opens prompting you to select your volume of production as shown in figure 61 below. The chosen selection determines which type of manufacturing layout you may most likely be using.

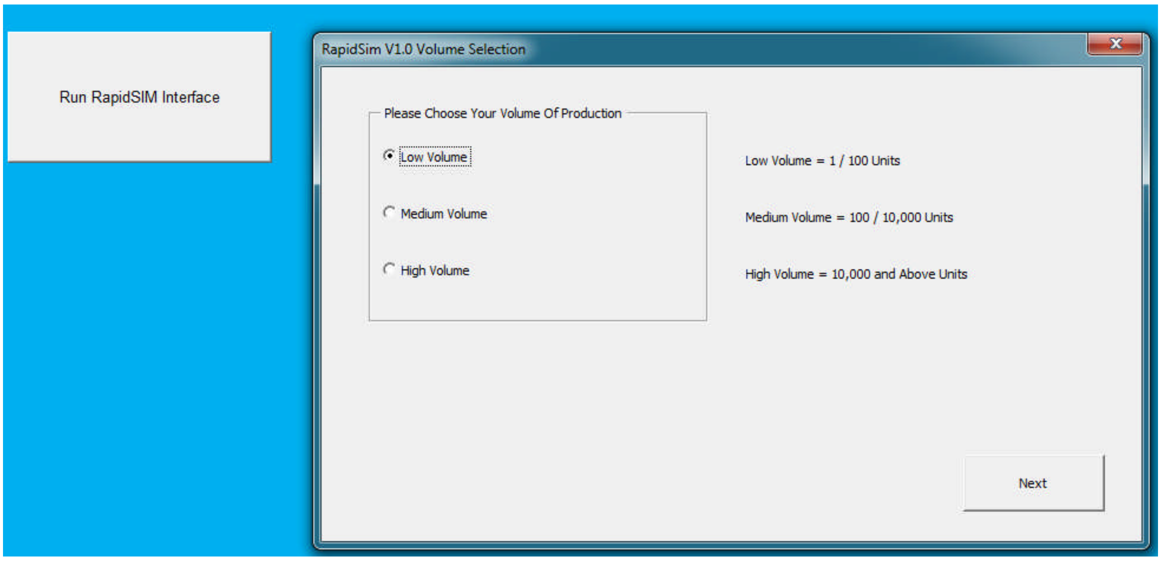


Figure 61: Volume selection

If low volume is selected you will proceed straight to the main interface window. However if medium or high volume Is chosen as shown in figure 62, the user will proceed to the System Selection and the Production type selection windows respectively. When medium volume is selected the user is given the choice of three production systems to choose from. Depending on the choice made the user would progress to the main modelling window where the pre-determined components relevant to the choosen layout are listed in List Box 1.

Depending on the system selection type chosen a pop up window appears informing the user of the chosen layout type. If at any time the user is unsure about their selection, clicking the "back" button at the bottom left corner of the selction window takes the user back to the main volume selection window where they can start over. When the user has made their selection, they can click on the next button to proceed with the model building process.

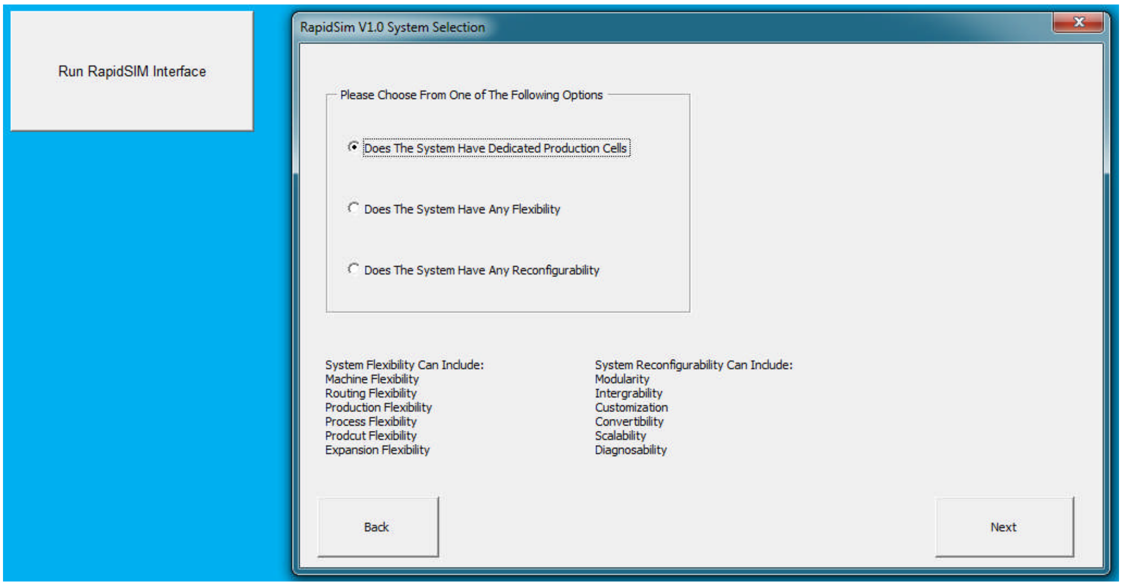


Figure 62: The System selection window

The same procees described above applies when the user chooses a high level of productiion. When high volume is selected as shown in figure 63 the user is given the choice of six production systems to choose from. Depending on the choice made the user would progress to the main modelling window where the pre-determined components relevant to the choosen layout are listed in List Box 1.

A pop up window appears informing the user of the chosen layout type. The user is given the option of using the “back” button at the bottom left corner of the selction window to restsrt the volume selection process if needed. When the user has made their selection, they can click on the next button to proceed with the model building process.

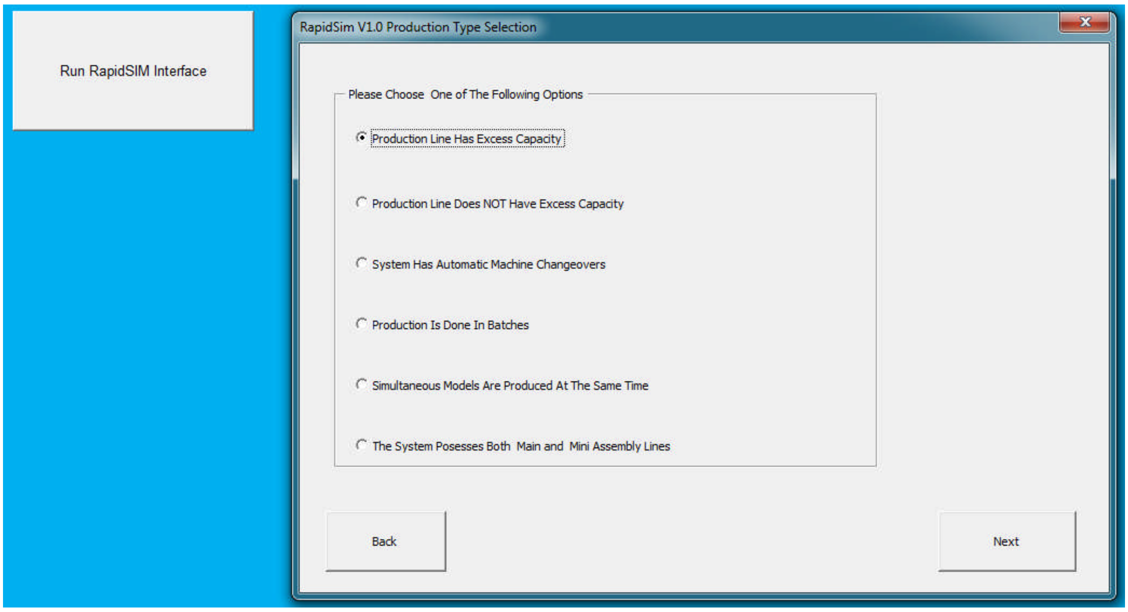


Figure 63: The Production type selection window

Building a Simulation Model:

After familiarising themselves with the workings of the RapidSim interface, users are now in a position whereby they can create a simulation model quickly and efficently. The folowing steps are itended to guide the user throug the model building process;

Step 1, Adding Components:

When the user progressess through the volume selection process their choice of layout type is reflected by the type of components which arelisted in the first window or list box of the main interface window. The components which are automatically loaded into list box 1 represent the most common configurations that one would find in this particular layout type. The user can add components to the model by simply highlighting the model needed and then clicking on the “Add Single Component” button which is located directly underneath the list box window. Components can be added as many times as needed by simply repeating the steps above. The choice of components selected by the user will be shown in list box 3.

However the user may require certain components which have not been included in list box 1. In this case the user is directed to list box 2, where all the components which can be used in creating a model are stored. Users simply need to select the component needed and click the “Add Combined Components” button. This step can be repeated as many times as possible depending on the number of modules required. The choice of components selected by the user will be shown in list box 3. The two list boxes mentioned above can be seen in figure 64 below.

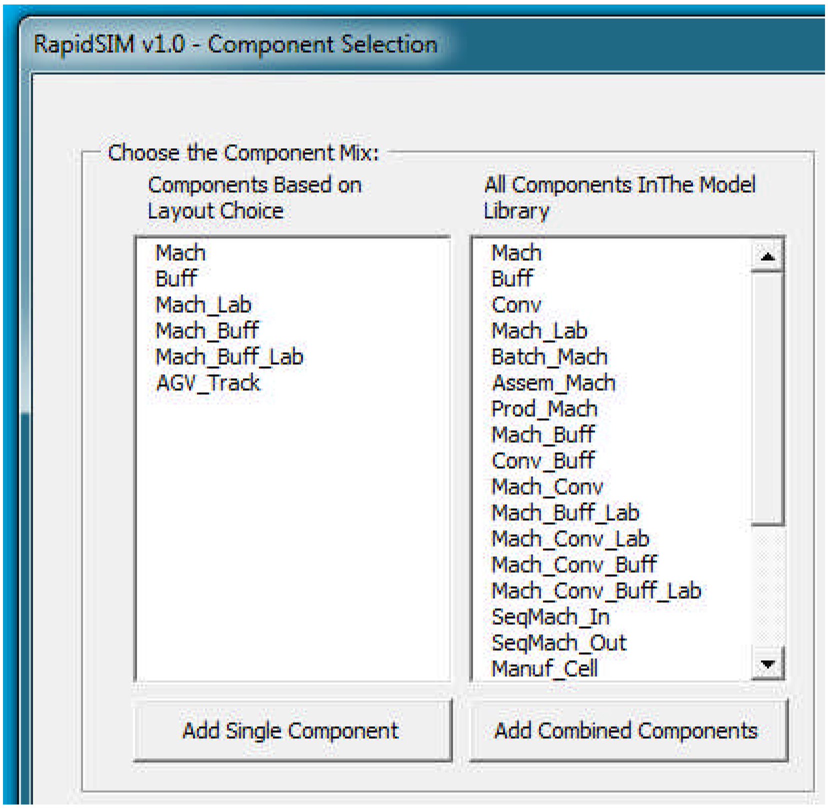


Figure 64: The Component Windows

<u>*Step 2, Deleting Components:*</u>

The components which have been chosen after step 1 are now listed in list box 3 “the list of selected components”, with the components displayed in no particular order. At this stage of the model building process the user can add more components to the model if they so desire. Also the user is now given the opportunity to delete any components which are not needed for the model by simply higlighting the unwanted component and then clicking the delete button which is located directly under the list box window. The list box as well as the delete button can be seen in figure 65 below.

Step 3,Choosing the order of route inputs:

Having decided on the components that are to be used in the model it is now necessary to decide on the order of their route inputs, i.e the order in which the modules will appear in the completed model. This process is done by using the componet choice forward and back buttons. Components are added to list box 4 by selecting the component and then clicking on the component choice forward button. When a component has been selected using this process the component is removed from list box 3 and now appears in list box 4. This process helps the user to eliminate mistakes in the order of route inputs. If however, a component is added to list box 4 and the user wishes to remove this component, the user simply needs to highlight the unwanted component and click the component choice back button. The component is removed from list box 4 and now reappears in list box 3. This process needs to be completed until the chosen components for the model are listed in list box 4. The order in which these models appear in list box 4 determines how these models will be replicated in the main witness modelling window. However it should be noted that only the components which are in list box 4 will be used in creating the model. If the user changes their minds about using more or less components this can be easily adjusted and represented in the final model.

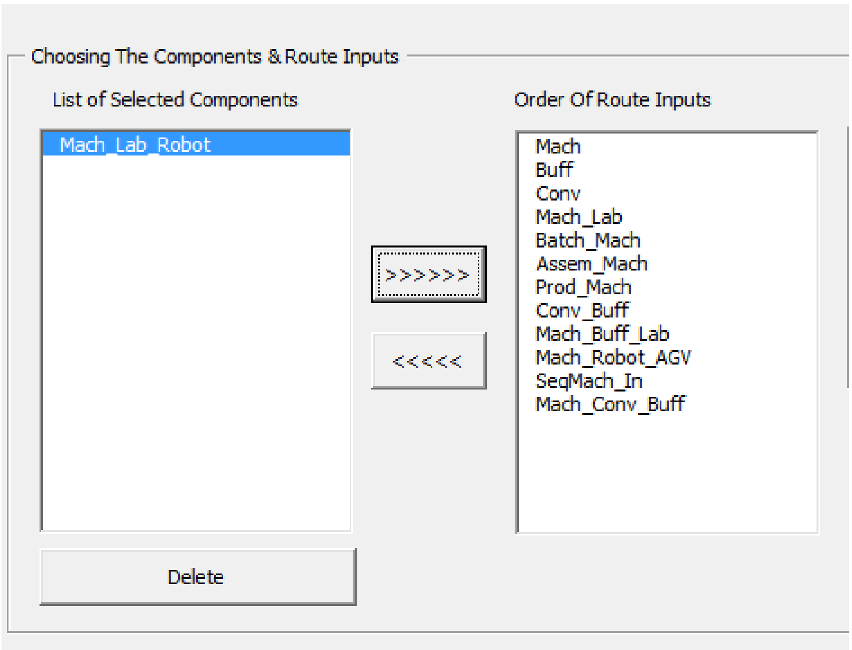


Figure 65: The List of selected components and the order of route inputs.

<u>Step 4, Choosing the Component Position:</u>

The next step in the model building process aims at assigning a co-ordinate position to the component. This step is necessary as selecting varying co-ordinate positions elimnates the “pile up” of chosen components when the model is replicated onto the main modelling window in Witness. Also this step helps the modeller to visualize what the completed model may look like as they are able to position the modules to best represent their actual layouts. Positioning the components or modules takes place by highlighting the componet in list box 4 (starting from top to bottom) and then selecting the components position on the component position window. A rectangular box highlighted in red is shown in the component position window, giving the user a visual idea of where the component will be placed. When the user has decided on a X and Y position for the component the user needs to click on the “Set Value” button to lock the chosen position in place. This process needs to be repeated until each component is positioned where needed in the model. Howver If the position of a component needs to be changed after the set vale button has been clicked, the user simply needs to highlight the component and select new X and Y positions, then set the value for the component once more. Figure 66 below displays the component and co-ordinate position window.

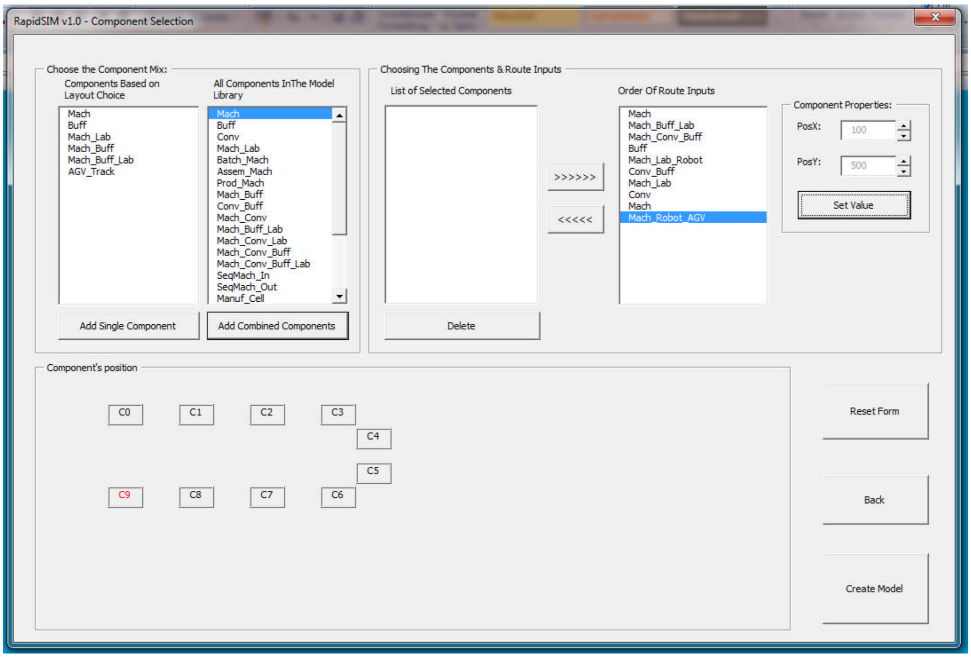


Figure 66: The Component Position Window and the X & Y Co-ordinate window.

Step 5, Creating the Model:

One of the main advantages of the RapidSim interface is in its ability to drive or control the Witness simulation package. What this basically means is that the Witness model file (.mod file) does need to be open when the interface is being used. All the model building activity takes place on the excel screen and not on the Witness model page. After the components have been positioned and their values set using the Component Position Window (*the position of the icon in this window depicts the position the icon will appear when it is replicated onto the Witness screen*) and all the necessary information has been filled in on the interface, the end user needs to click the “Create Model” button to execute their choices. The choices made in the interface shows up as a replicated model in witness. However, before this happens the user is guided to one last selection window which prompts them to select the Witness .mod file they wish to transfer the data to from the interface. The main reason behind this feature is ensure that the data is transferred to the correct Witness file every time a new model is built. Figure 67 below shows the window prompting the user to select the appropriate witness.mod file.

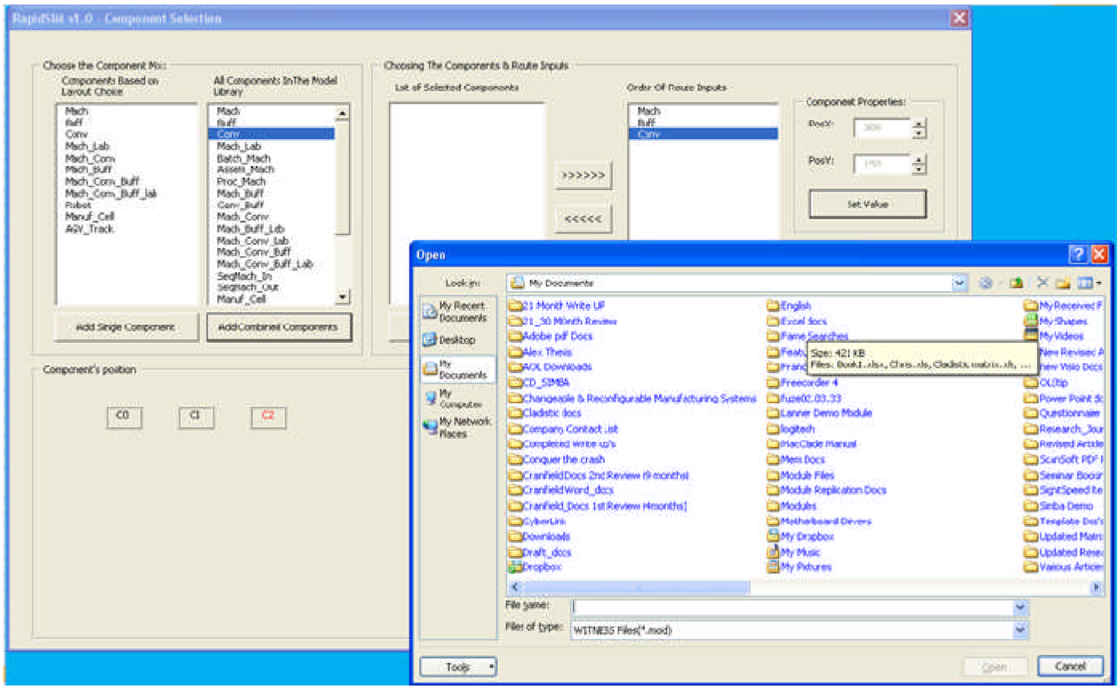


Figure 67: The File Selection Window

After selecting the appropriate witness.mod file the data stored temporarily in the interface is then transferred into the witness simulation engine. On successful transfer of the data and construction of the model, the user is prompted via a message box in the interface window informing the user that the model has been created successfully. Figure 68 below shows an example of a completed model in witness.

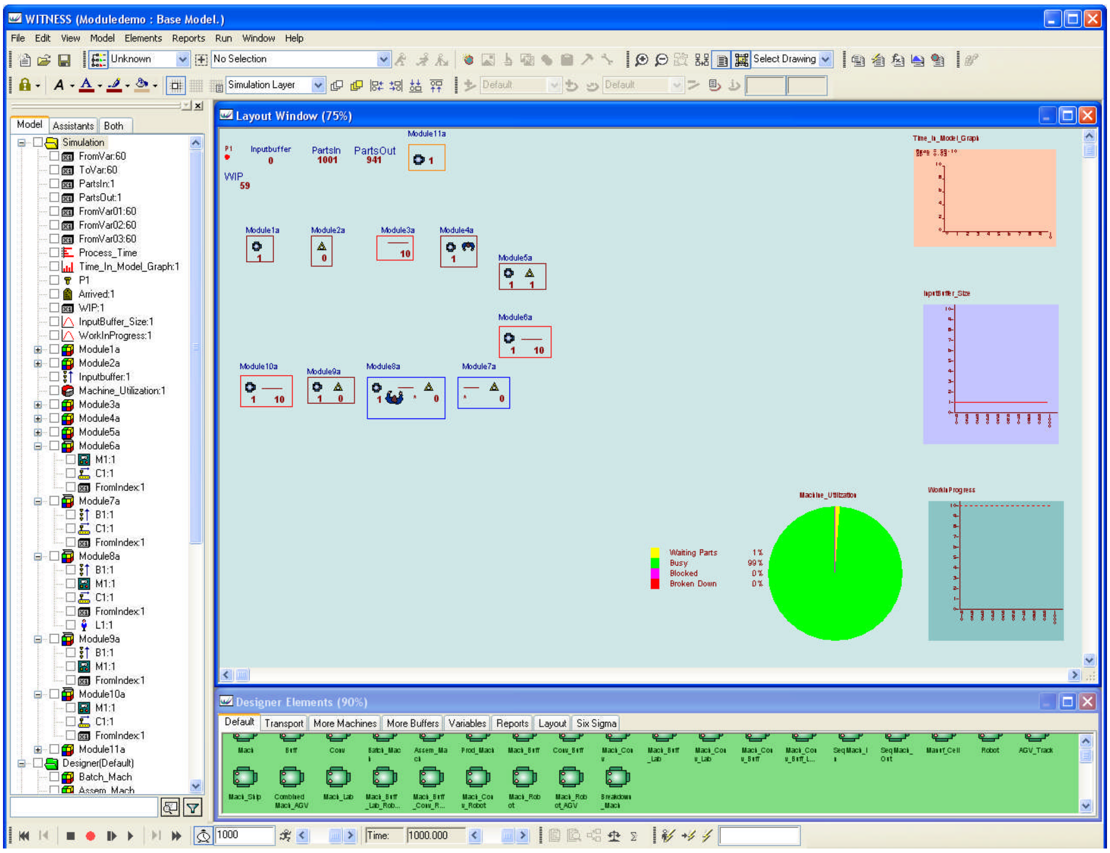


Figure 68: The completed witness model

<u>Rearranging the Model:</u>

In RapidSim users can quickly rearrange the model by simply changing the order of the route inputs. The components which are listed in list box 4 can all be transferred back to list box 3 using the component choice back button. The new order of rout input can be chosen based on the user's new requirements. The components are once again transferred via the component choice forward button into list box 4 based on their new routing. The co-ordinate positions for the new layout are then chosen, their values set and the model created.

Bypassing Elements in a Model:

It may be necessary during the course of developing the simulation model to ascertain how the model would behave if certain components were not included in the model. This process of "bypassing elements" can be carried out quickly and easily via the RapidSim interface. As all the components which are included in the model are stored in list box 4, the user needs to change the order of the route inputs in order to bypass the unwanted components. This can be done by selecting the component or components which are not needed in the model and then clicking on the component choice back button to transfer the component back into list box 3. The component no longer shows up in list box 4. The user can click on the create model button to build the new model. If the position of the components needs to be altered the user needs to set their new values using the X and Y co-ordinates and the set value button.

Resetting the Model:

As with any model building process they may come a time when the user may wish to "wipe the slate clean" and start again. In the context of the RapidSim interface this can be done via the "Reset" button. Clicking the reset button removes all pre-loaded data i.e., the layout type components from the interface and as such all the information which is stored in list box 1 is removed. The user is left with all the components shown in list box 2 from which to construct the model.

The Witness Model:

As the excel based interface is used to drive the witness simulation engine there are certain functionalities of the witness demo page which the user needs to be familiarize themselves with. However, before this can happen it is necessary to understand what information is presented in the witness demo page. Figure 69 below shows the main witness modelling window and the key components of the witness demo page.

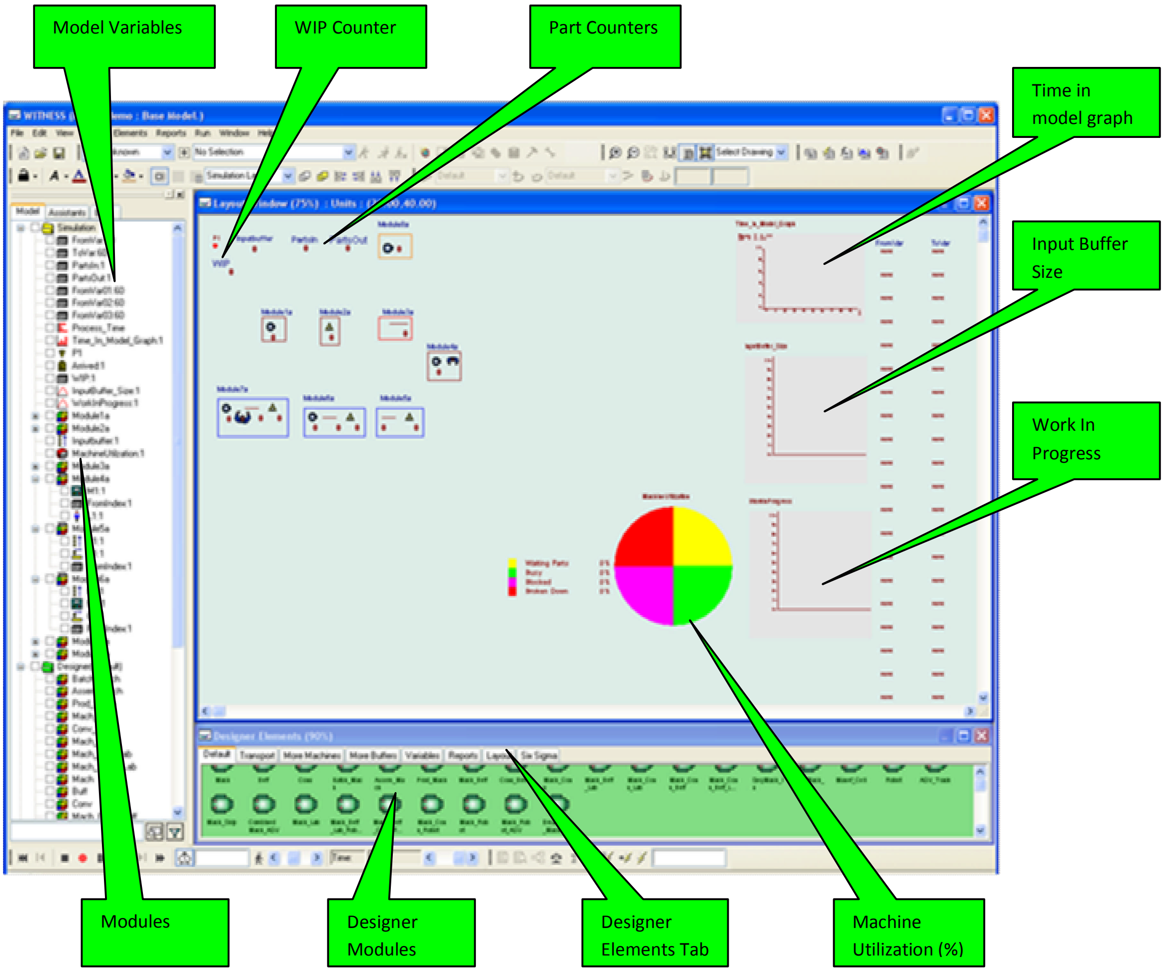


Figure 69: The Main Witness Modelling Window

Model Variables:

It is important that users understand how the witness demo file works. Firstly all of the programming in Witness is done within the context of variables. Variables are used as a means of obtaining flexibility and repeatability when using the witness simulation software. As these variables are used to program the modules it is advisable that they are not deleted from the model. Deletion of any variable would render the model prone to errors and loss of functionality. The variables used in the model correspond to the data stored in the excel interface and they facilitate the data transfer process. These variables are listed below and are as follows;

Parts In:

This variable is used to track the number of parts that enter the system.

Parts Out:

This variable is used to track the number of parts that leave the system after completion.

WIP Counter:

The WIP counter is used to track the number of parts that are currently being worked on within the system and it works by counting the number of parts that enter and leave the system. The difference between the number of parts going in, and the number of parts going out, accounts for the number of work in progress that is in the system.

Modules:

The modules which have been created for the template based modelling library are all stored as designer elements within the witness model and are displayed within the data tree. The modules stored in the witness demo page correspond to the excel equivalent which have been programmed into the RapidSim interface. The modules are all programmed to have interconnectivity as well as logic and their makeup cannot be changed once they are saved as part of the Witness demo file. When data is transferred via the interface into the main modelling window in witness, the executable code first scans for the presence of these variables and only when these are found does the data transfer process take place. However it should be noted that when data is transferred into the main modelling window the data stored in the replicated modules can be changed to meet the end user requirements. Simply double clicking on the module or element brings up the witness modelling window for the component, allowing the end user to modify cycle times, quantities etc.

Designer Elements Tab:

This can be found at the bottom of the page under the window titled designer elements. The designer element tabs store the visual representations as well as the statistical tools that are needed to construct the simulation model. There are 7 tabs that are loaded by the systems default setting, however as pre-built modules are used in developing the model it was necessary to create an additional tab titled “Default”. Under this tab all the modules which were created to aid in the model building process are stored.

Whenever a new module is introduced into the main demo page it is necessary to firstly create this module in the data tree. After this has been done the module can then be renamed and mapped. Mapping is necessary in order to link the module created to the physical module which exists. This process allows witness to store the path or address of the physical module which it then refers to when model replication takes place. However, it should also be noted that for any of this to work the layout tab in the main model window needs to be selected at all times, thus making it the default tab for this process.

Designer Modules:

The designer modules are stored under the Default tab and they represent the total number and configuration of modules which can be used in the model building process. As mentioned above these modules are created then mapped and they can be added to the model as a completed module file. Any modification needed to these modules, takes place out of the main model demo page. The module has to be opened on a separate modelling window and the variables remapped before any changes can be made. The module then needs to be saved and remapped for future use.

Time in Model Graph:

This graph details the average time the part spends whilst being worked on in the system. The information detailed in the graph is compiled in a histogram format and is compiled automatically by the system, thus requiring no input from the end user.

Input Buffer Size:

This graph is used to measure the number of parts that are stored in the input buffer. The process works by simply counting the number of (NPARTS) that enter the input buffer.

Work in Progress:

This is a graphical representation of the work that is being processed within the system after an allotted time period. The number of WIP is calculated by calculating the difference between the numbers of parts going into the system against the number of parts coming out. This value is represented automatically in the time series graph located in the main demo page and requires no input from the user.

Machine Utilization:

This function is used to measure the percentage of any active element that is being utilised at any given time. In order for this function to be generic enough to work in any replicated layout, the machine utilization pie chart is left blank on the main modelling witness page. If the user wishes to capture data relating to any active element within the layout they need to detail the pie chart. This process can be done by applying the following steps;

- Create the model via the RapidSim interface
- Move to the main witness demo page and double click on the blank pie chart.
- Select the element states tab
- Select / check display element states
- Click on the drop down arrow that appears. A new window will open prompting the user to select the element they wish to detail. Scroll through the list and select the element by double clicking on it. Once completed switch to the General tab.
- From the table that appears delete the settings you do not want to record. Once complete click on the OK button.
- On the main witness page right click, and then click on display. From the detail box that appears select draw, then under name select key.

- Click on the first button (which resembles a pencil) to detail the key. When the window opens check the box that says show percentages and then ok.

- Position the mouse anywhere on the main demo page and click to display the key. Reposition the key by clicking and dragging if necessary.

The Data Transfer Process:

The Excel driven user interface uses the Macros which are enabled within the software's developer tab to transfer data between Excel and Witness through. This data transfer is done through the use of visual basic scripting. Visual basic scripting is a scripting language which has been developed by Microsoft and which has been modeled on its more widely known counterpart Visual Basic. VBS has been developed in order to facilitate a language which fosters fast interpretations for persons working in the Microsoft environment and it use the Component Object Model to gain access to elements within the environment it is being used. The macro is specifically programmed to check on the status of the model being developed and if the macro detects that the model is in the "run mode" the macro pauses the model and transfers the data onto the model window in Witness. This feature gives users the ability to change the data used in the model even when the model is operating in "run time". The use of macro for transferring data from a Microsoft Excel file shows how the application of a desktop resource can facilitate making simulation tools easier to use as most persons are familiar with some or all of the functionalities of Microsoft Excel.

Creating a Module

In order to create a module it is necessary to firstly create a witness demo page that contains all the necessary variables which are needed in the model. This page can be saved and used as the base from which to recreate all other modules. After this has been done a module can be created by performing the following steps

- Select the component or components that will make up the module

- Enter the programming functionality for each component. As the logic is programmed using variables it is important that the function or commands given to each component be programmed using the variables as reference.

- Link components where necessary

- Left click and drag to select all the components that will make up the module. When selected click on the create module button which appears in the toolbar.

- Click on the module superlock button which can be found on the data tree window to lock all the components together. This is vital as without this the components in the module will not replicate as one completed module. Instead they will replicate onto the witness demo page as individual components.

- Click on file then Save As and give the module a name. Choose .mdl as the file type and follow the instructions to save the module.

Making Changes to a Module:

Once the module has been created it can be changed or modified by following a few simple steps

- Open the witness software

- Click on file, open and select the module file which needs to be modified.

- Witness will prompt the user to remap the variables that were used to construct the file. Follow the instructions to remap the variables and once completed the module file would open

- Make the necessary changes

- Save the file and exit. (It will be easier to save the file using the existing file name as this would prevent having to remap the module within the main witness demo page).

Adding Modules to the Witness Demo Page:

Modules can be added to the demo page once they have been created and saved. The steps for adding a module are as follows;

- Open the main witness demo page
- Go to the designer tab and select the layout tab if it's not already selected
- Right click on any existing designer element and select clone from the drop down menu. A clone or copy of the module will be displayed in the designer elements window as well as in the data tree.
- Select the cloned module in the data tree and click once to rename the module.
- Move back to the designer tab window where he renamed module will now be displayed. Double click on the module and follow the instructions to map the designer module to the module file which has been created.
- Once completed click the "SAVE" button and exit the window.

Deleting a Module:

Deleting a module in the witness demo page is a lot easier than creating one and can be done in the following steps

- Identify the module that is to be deleted in the data tree
- Right click to select it.
- From the drop down menu that appears click on delete. (This will delete the module from the data tree as well as from the layout tab window.)
- Click on SAVE and exit the witness demo page.

APPENDIX 4: THE CASE STUDIES

RAHMAN ALAM

Model A: Building a Manual Simulation Model

Exercise 1: Build, link and run the simulation model.

Please build the simulation model as detailed in figure 1 below. Link all the elements (Inputs and outputs) using "Push" and "Pull" rules and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

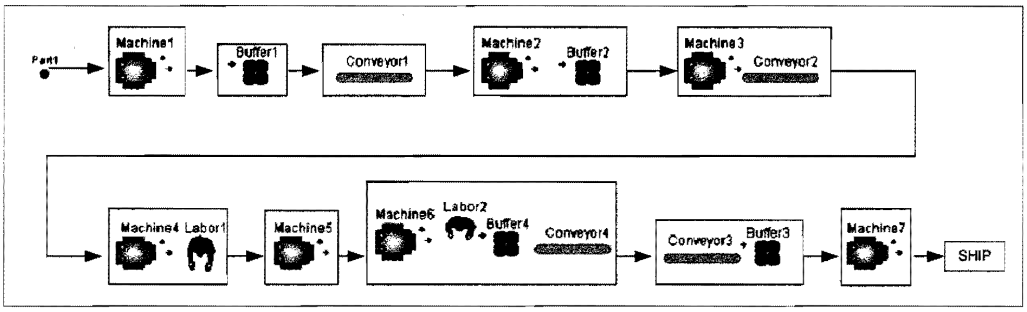


Figure 1: The Manual Model

The information presented in Table 1 shows the component and model requirements for the simulation model constructed in Figure 1.

Table 1: Component and Model requirements

Component	Function	Model Requirement
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 1	1	2 ✓	3	4	5

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly alter the position of the components in the layout to represents the model shown in figure 2 below. Link all the elements (Inputs and outputs) as before and run the model when completed. The component and model requirements for this exercise remain the same as in exercise 1.

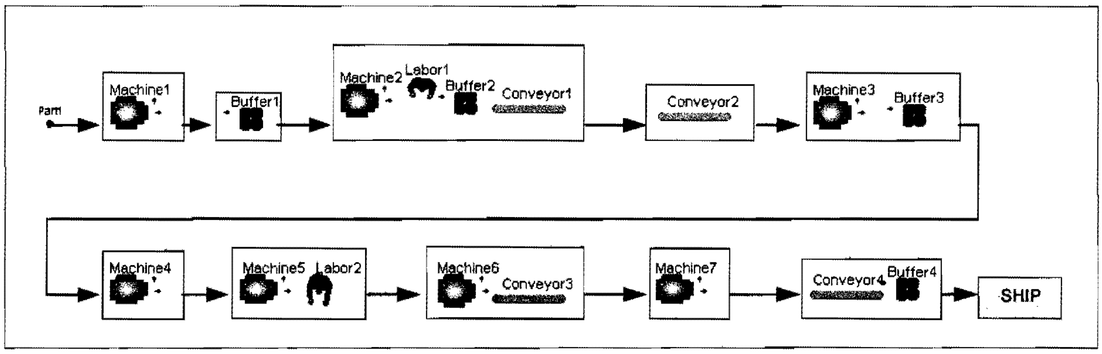


Figure 2: The Amended Model

Note to User: *In order to create the working model shown in figure 2, some of the previous inputs and outputs used in figure 1 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy
Exercise 2	1	✓	2		3		4		5	

Exercise 3: Altering the part route

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 3 below. Link all the elements (Inputs and outputs) as before and run the model when completed.

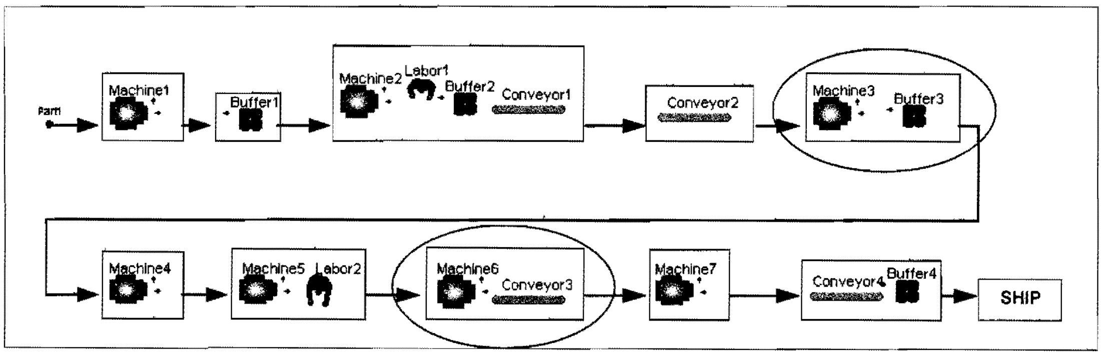


Figure 3: Bypassed elements

Note to User: *In order to create the working model shown in figure 3, some of the previous inputs and outputs used in figure 2 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult							Easy	
Exercise 3	1		2		3		4	✓	5	

Exercise 4: Key Performance Indicators

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

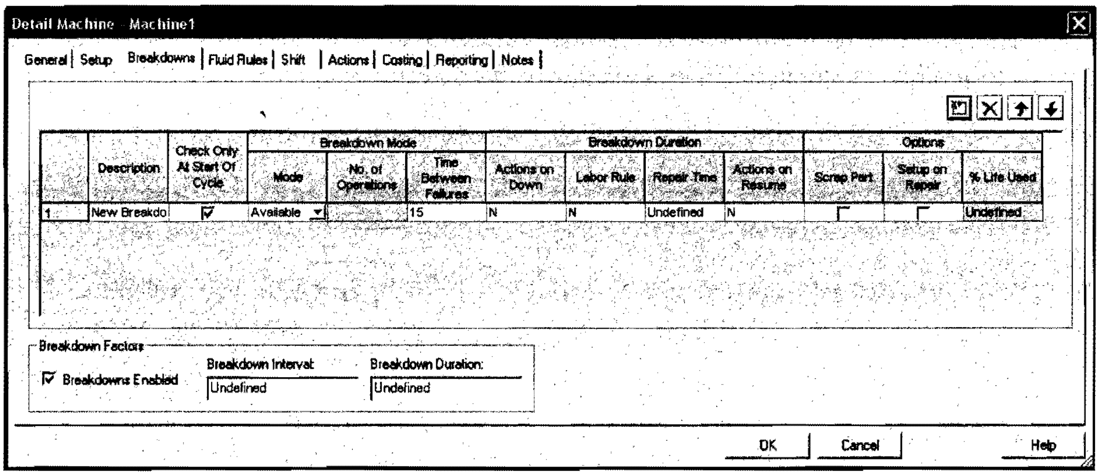


Figure 4: Detailing the Machine Breakdown

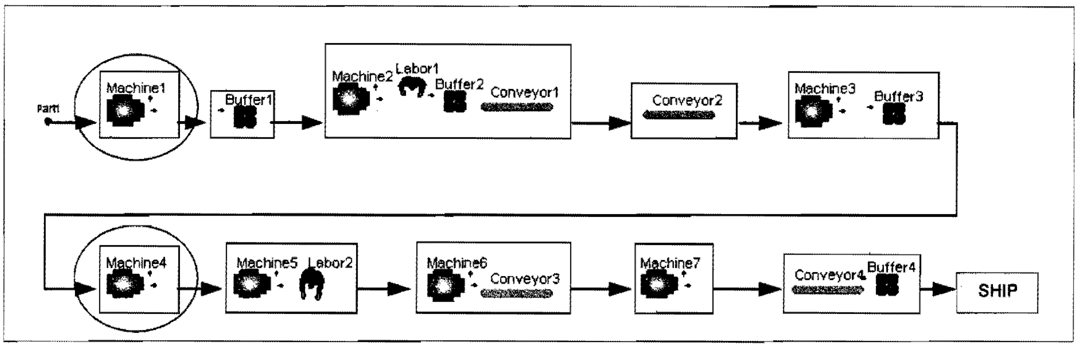


Figure 5: Model with machine breakdowns

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 4" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 4". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	—	
Number of work in progress (WIP)?	—	
The Average Machine Utilisation?	34 %.	100 %.

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4a	1	✓	2		3		4		5	

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 5" as shown in Figure 6 of the model below.

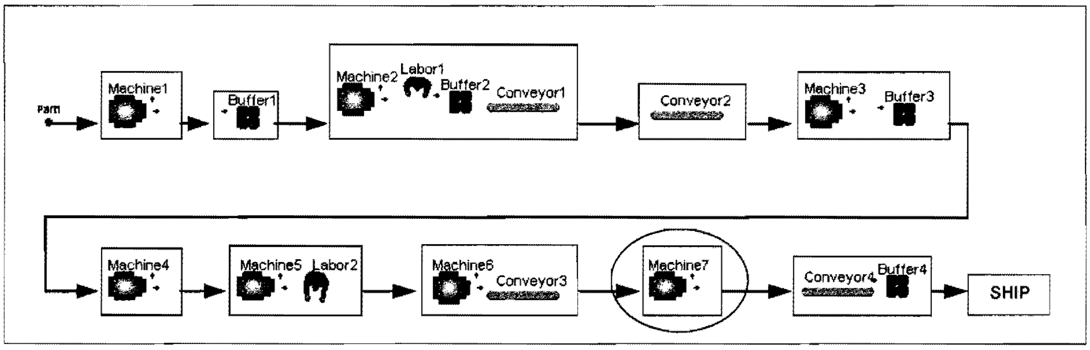


Figure 6: Machine breakdown

The breakdown which occurs in "Machine 5" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 7" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 7" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?		
Number of work in progress (WIP)?		
The Average Machine Utilisation?		

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4b	1	✓	2		3		4		5	

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes		No	✓

Time taken to construct the model	37 minutes.

Model B: Building the model using the RapidSim Prototype

Using RapidSim:

Step 1:

In order to use the RapidSim Interface you need to open the corresponding Excel File, which in this case is the "ModuleDemo.xlsm". This can be found on the desktop in the folder named "Interface Docs".

Step 2:

Double click on the "ModuleDemo.xlsm" excel file to open it. When opened click on the options button. In the pop up window that opens, select enable this content and then click on OK to proceed.

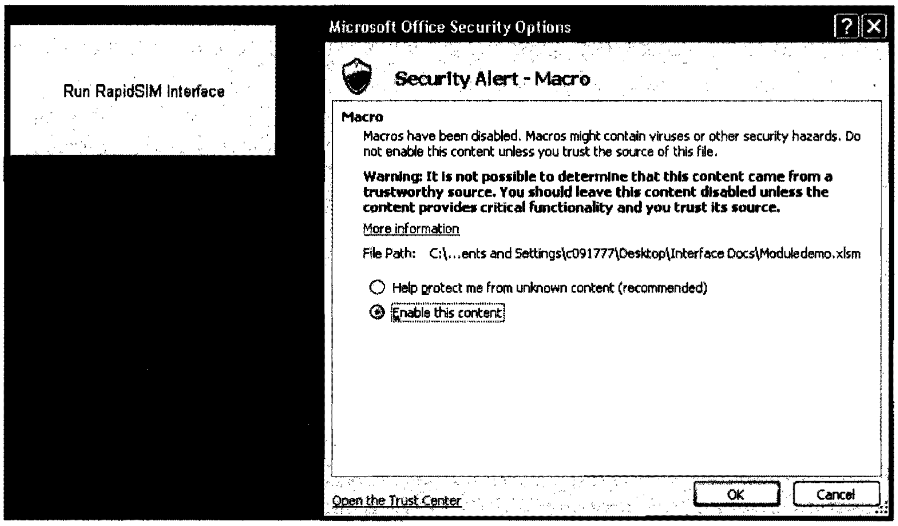


Figure 7: Enabling the system macro's

"Clicking on OK enables the macros's which are programmened in this workbook and it imparts full functionality to the interface".

Step 3

Click on the Run RapidSim Interface button. A new pop up window opens prompting you to select your volume of production. This choice determines which type of manufacturing layout you may most likely be using. Select one of the three options provided, and then click on the next button to proceed with the model building process.

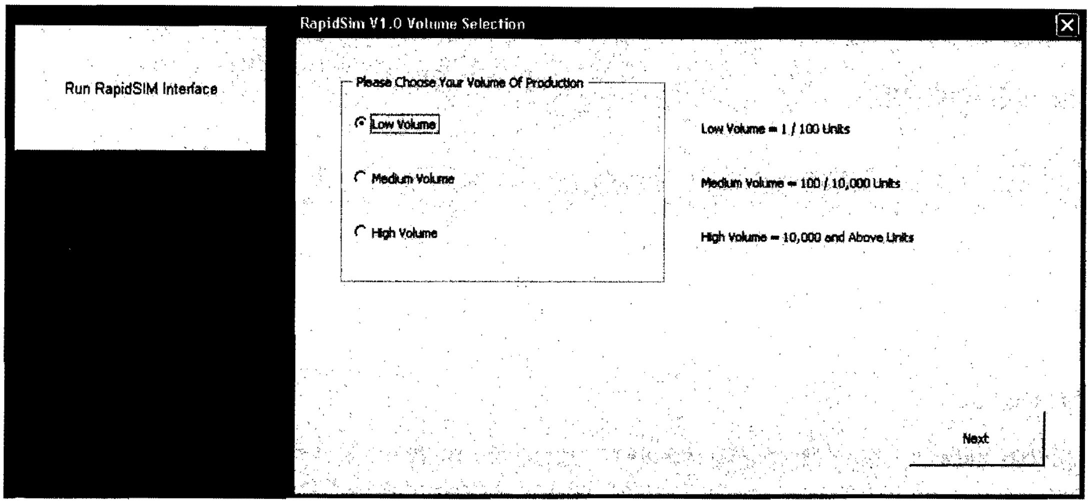


Figure 8: Volume selection

If low volume is selected you will proceed straight to the main interface window. However if medium or high volume Is chosen you will proceed to the System Selection and the Production type selection windows respectively. Clicking on the next button in either of these two frames will take you to the main modeling window.

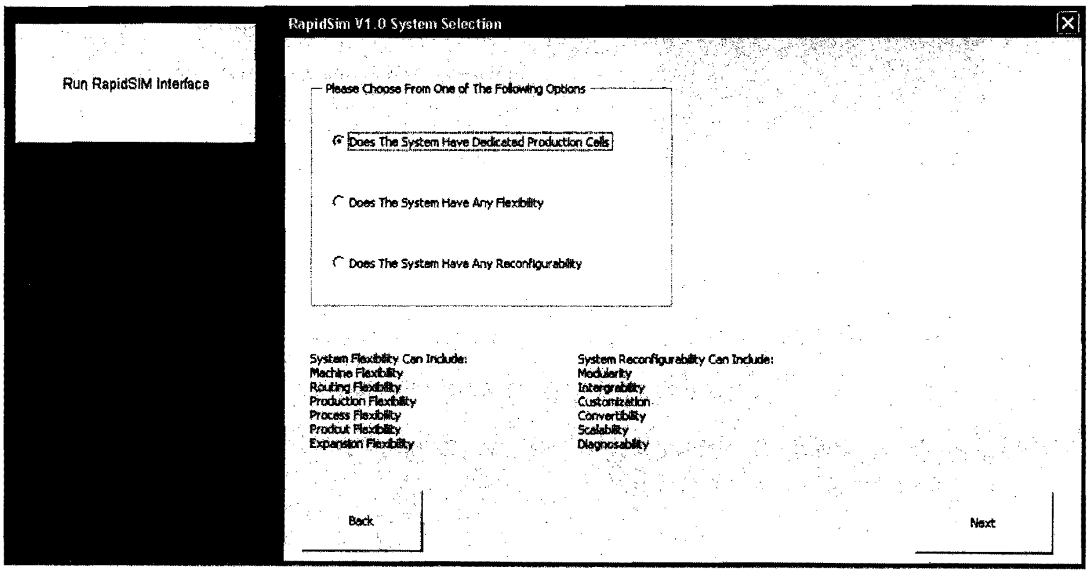


Figure 9: The System selection window

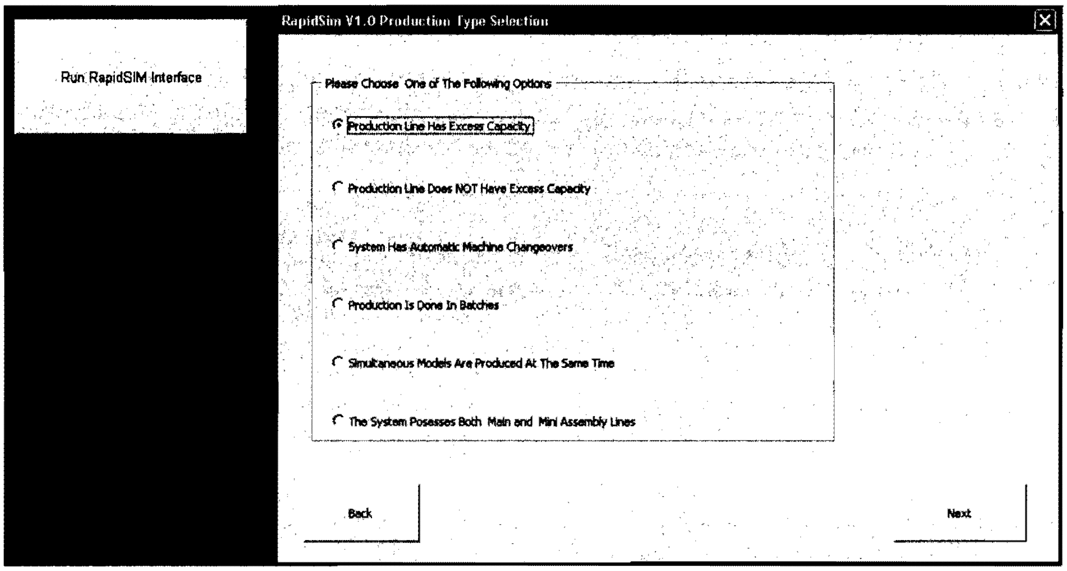


Figure 10: The Production type selection window

Step 4: The Main Interface .

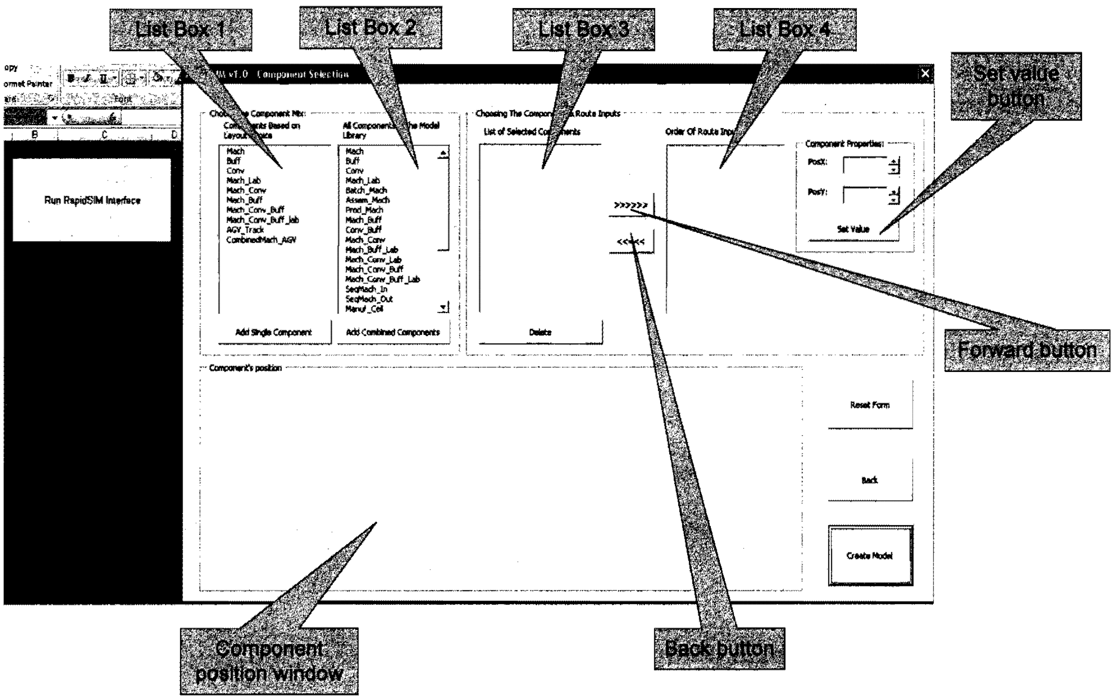


Figure 11: The main interface window

Exercise 1: Build, link and run the simulation model.

Please build the simulation model detailed in figure 7 below using the RapidSim Interface. Link all the elements (Inputs and outputs) and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

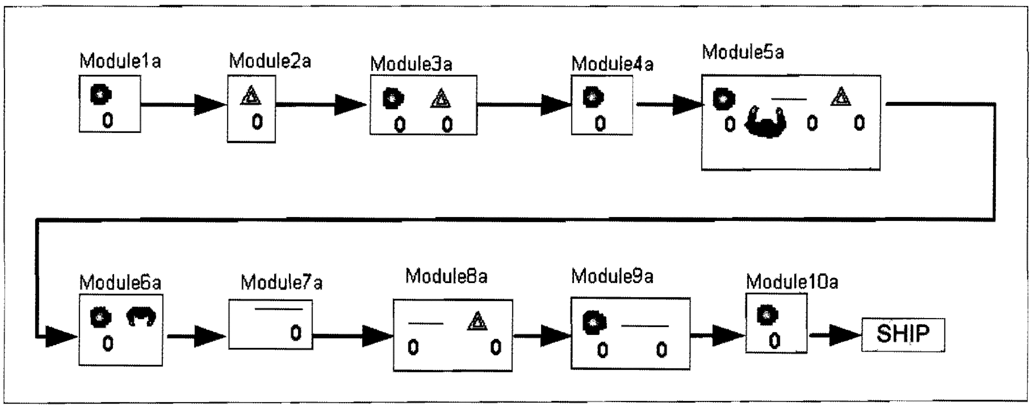


Figure 12: The RapidSim Model

The information presented in Table 2 shows the component and model requirements for the simulation model constructed in Figure 12.

Table 2: Component and Model requirements

Component	Function	Model Requirement
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

Note to User: *As the shipping machine is added automatically when the model is created it is not necessary for you to specify this machine in the model.*

To construct the model using RapidSim:

- Open the Excel file containing the RapidSim interface
- Enable the workbook macros

- Select the volume of production
- Select the modules then click the add component / add combined component button. Repeat this step to add as many modules as needed
- Select the order of route inputs
- Set the module position using the X & Y co-ordinate system
- Click on create model

Table 3 below details what modules are needed and the quantities required in order to build the model shown in figure 12

Table 3: Module and quantity requirement

Module Needed	**Quantity**
Machine (Mach)	3
Buffer (Buff)	1
Conveyor (Conv)	1
Machine & Buffer (Mach_Buff)	1
Machine & Conveyor (Mach_Conv)	1
Machine & Labor (Mach_Lab)	1
Conveyor & Buffer (Conv_Buff)	1
Machine & Conveyor & Buffer & Labor (Mach_Conv_Buff_Lab)	1

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy	
Exercise ~~45~~ 1	1		2		3		4		5	✓

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly rearrange the modules in the layout to represents the model shown in figure 13 below. The component and model requirements for this exercise remain the same as in exercise 1.

<u>**Note to User:**</u> *This can be done by altering the order of route inputs and then setting the X & Y co-ordinates.*

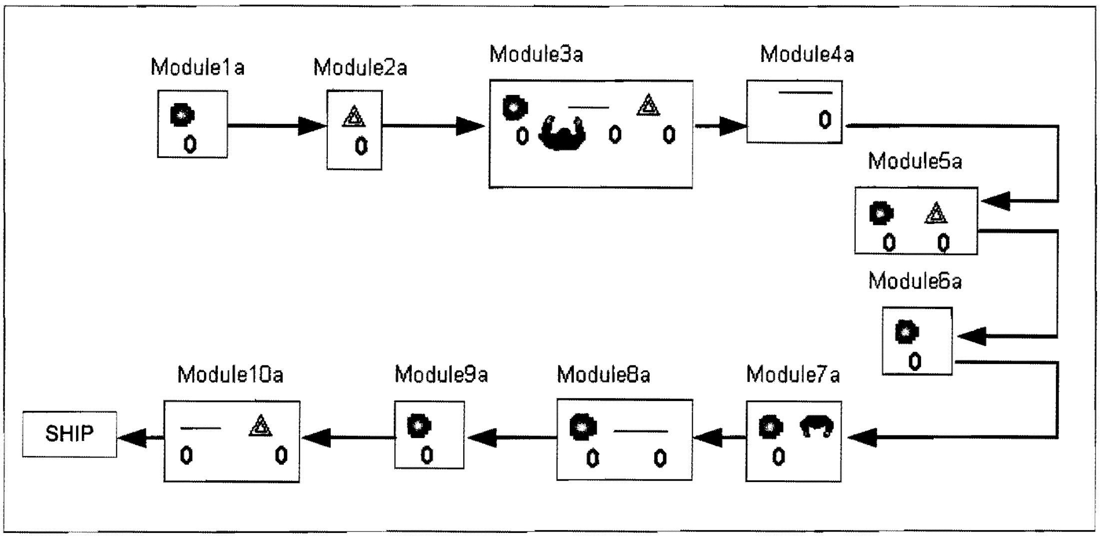


Figure 13: The re-arranged model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise ~~46~~ 2	1		2		3		4		5	✓

Exercise 3: Altering the route & model shape

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 14 below. Run the model when completed using the parameters set aside in table 2.

<u>Note to User:</u> *This can be done by deleting the unwanted modules and then setting the X & Y co-ordinates.*

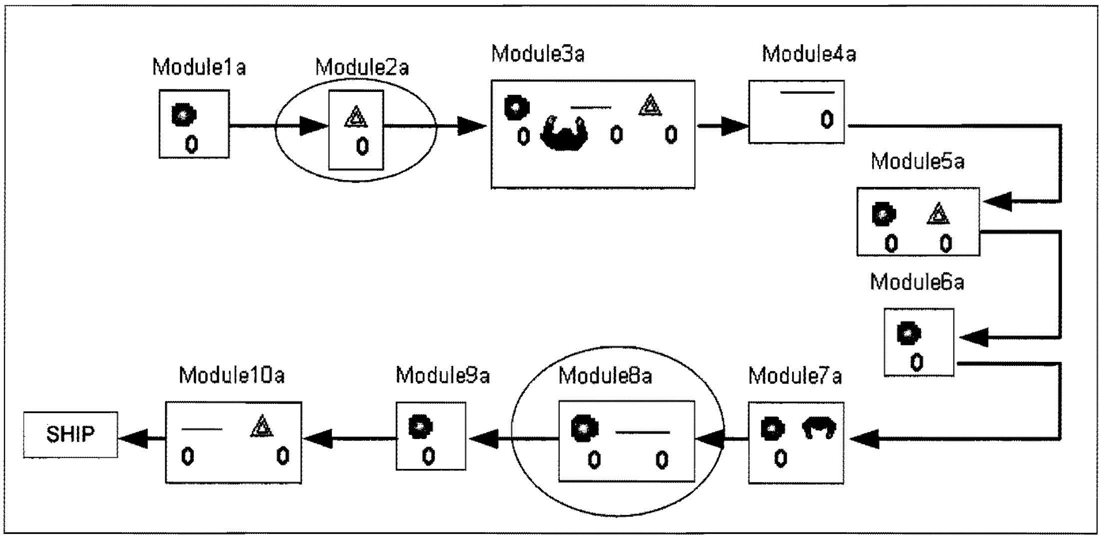


Figure 14: The re-routed model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise ~~4~~ 3	1		2		3		4		5	✓

Exercise 4: Key Performance Indicators

General guidelines:

To measure the lead time:

- On the witness demo screen right click on the graph titled "Time_In_Model_Graph" and scroll to and select "statistics". This will display the lead time.

To measure the work in progress (WIP):

- On the witness demo screen right click on the graph titled "WorkInProgress" and scroll to and select "statistics". This will display the WIP. *Alternatively you can read from the WIP value located at the top left hand corner if only a value is required and not an average.*

To measure the Input Buffer Size:

- On the witness demo screen right click on the graph titled "InputBuffer_Size" and scroll to and select "statistics". This will display the lead time.

To count the number of Parts Into the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsIn".

To count the number of Parts out of the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsOut".

To measure the machine utilization:

- Double click on the pie chart in the witness modelling screen (moduledemo.mod)
- Change the refresh interval to 10 unit time then click on the element states tab
- Check the display element state box then select the component to be measured from the drop down list by double clicking on it
- Click on the general tab and delete numbers 4, 6, 7 and 8 from the sectors list then click on ok.
- If the machine utilization for more than one component needs to be measured, simply right click on Pie001 in the model window and select clone. Move the cursor to the witness screen and click. This creates a new pie chart called Pie002 and so on. Follow the steps above to measure the utilization for the component/components.

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

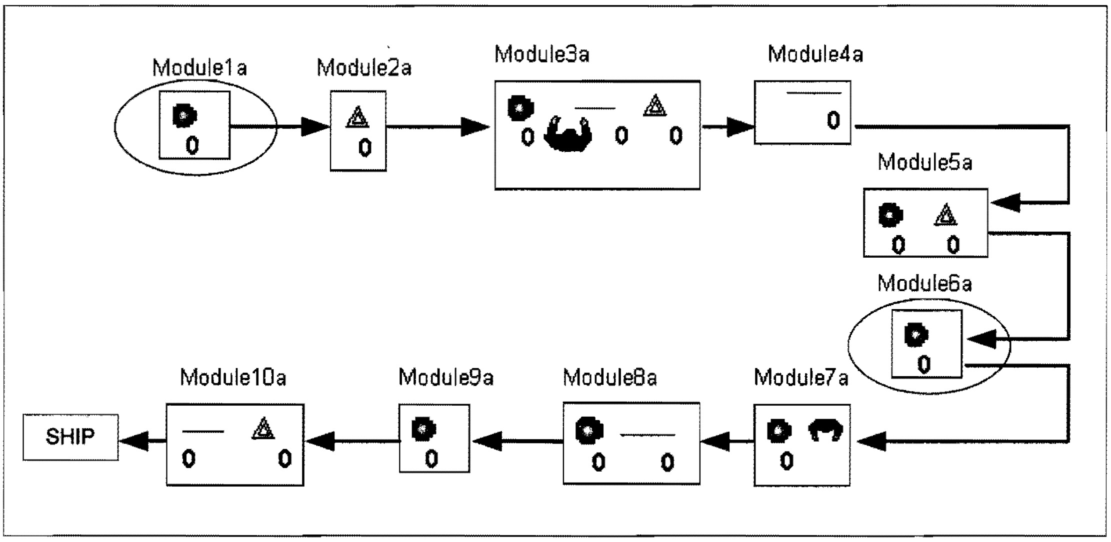


Figure 15: The breakdown model

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 6" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 6". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	428.	638.
Number of work in progress (WIP)?	429.	697.
The Average Machine Utilisation?	60%.	31%.

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 9" as shown in Figure 6 of the model below.

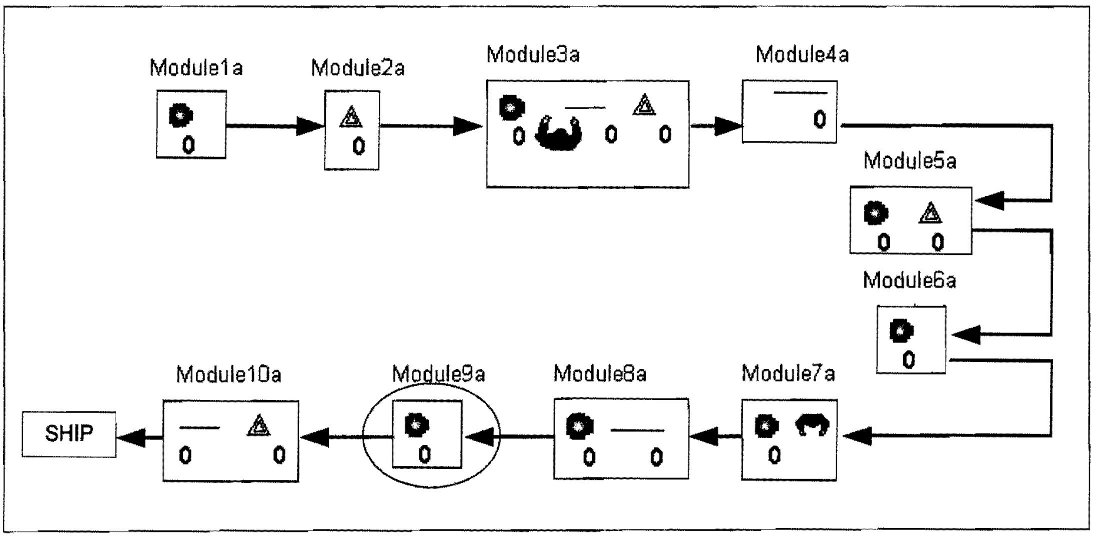


Figure 16: Machine breakdown

The breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 9" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?	698.	453.
Number of work in progress (WIP)?	705	454
The Average Machine Utilisation?	30%.	55%

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4b	1		2		3		4		5	✓

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes	✓	No	

Time taken to construct the model	13.28 seconds.

If you are confident with the use of the prototype, try building the more complicated model shown in figure 17 of a complex manufacturing system.

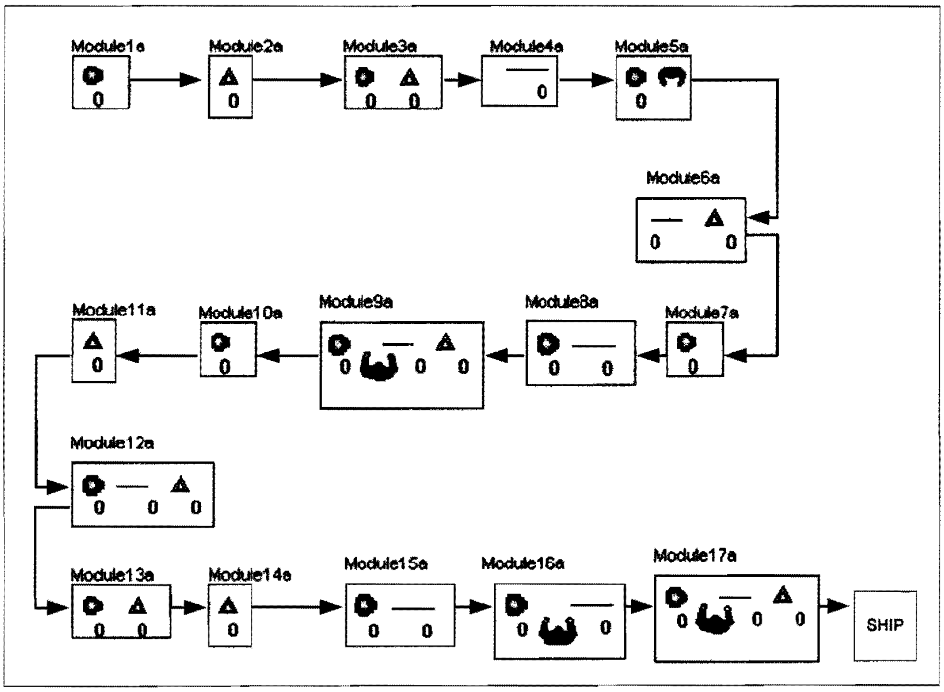


Figure 17: The complicated model

User Feedback:

This following questions put forward in this section of the validation process are to measure to what extent the prototype can help users in the model building process. Please tick the box numbered between 1 – 5 depending on the relevant judging criteria's given.

1. Experience of using Witness Simulation (please tick)

How long have you been involved in the area of simulation and model building?

[redacted]	✓	[redacted]		[redacted]		[redacted]	

2. Usage of Witness software (please tick)

During Lectures Only	✓
During group projects	
During thesis project	
Before coming to Cranfield University	

3. Usability

How easy / difficult is it to follow instructions in using the prototype?	1		2		3		4		5	✓
How easy / difficult is it to navigate around the interface?	1		2		3		4		5	✓
How easy / difficult is it to use the prototype?	1		2		3		4		5	✓

4. Speed

How slow / fast is it to construct a model using the prototype?	1		2		3		4		5	✓
How quickly can changes be made to the model?	1		2		3		4	✓	5	

5. Performance

How easy / difficult is it to measure the key performance indicators using the prototype?	1		2		3		4	✓	5	
Are the tools provided to measure the performance indicators useful?	1		2		3		4	✓	5	

6. Flexibility

How easy / difficult is it to create components / modules?	1		2		3		4		5	✓
How easy / difficult is it to rearrange the physical layout of a model using the prototype?	1		2		3		4	✓	5	
How easy / difficult is it to alter the physical routing of parts using the prototype?	1		2		3		4	✓	5	
How easy / difficult is it to bypass elements in a layout using the prototype?	1		2		3		4		5	✓
How easy / difficult is it to model "breakdowns" using the prototype	1		2		3		4	✓	5	
How easy / difficult is it to link components and run the model using the prototype?	1		2		3		4		5	✓
How flexible is modelling with the prototype compared to building models manually?	1		2		3		4		5	✓

7. <u>Usefulness</u>

The prototype will help in the model building process	1		2		3		4		5	✓
The prototype will help reduce the overall model building time	1		2		3		4		5	✓
Using the prototype allows me to create physical components easier and faster.	1		2		3		4		5	✓
Linking and running the modules / components can be done easily and effictively	1		2		3		4		5	✓
Switching any element On / Off and re-linking the model can be done easily	1		2		3		4		5	✓
The prototype has potential for improving the model building process	1		2		3		4		5	✓

8. <u>Comments / suggestions</u>

An effective way to model and measure without having to go through the hassles associated with building a model in witness - highly efficient and a great ~~eff~~ experience all in all.

Afeef Asali

Model A: Building a Manual Simulation Model

Exercise 1: Build, link and run the simulation model.

Please build the simulation model as detailed in figure 1 below. Link all the elements (Inputs and outputs) using "Push" and "Pull" rules and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

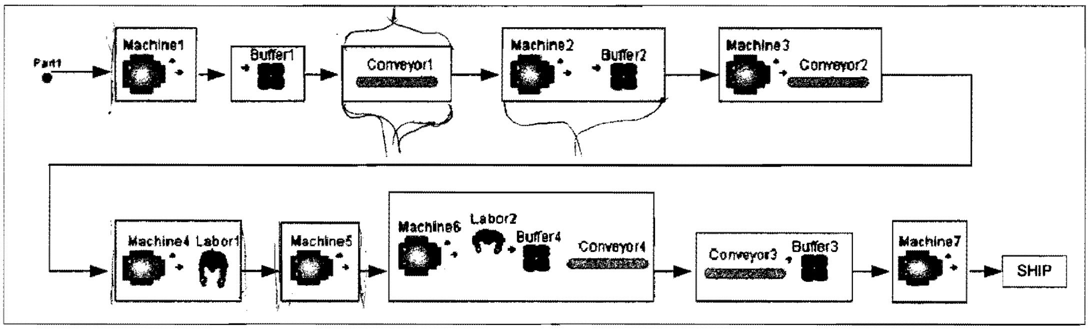


Figure 1: The Manual Model

The information presented in Table 1 shows the component and model requirements for the simulation model constructed in Figure 1.

Table 1: Component and Model requirements

Component	**Function**	**Model Requirement**
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 1	1	2	3 ✓	4	5

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly alter the position of the components in the layout to represents the model shown in figure 2 below. Link all the elements (Inputs and outputs) as before and run the model when completed. The component and model requirements for this exercise remain the same as in exercise 1.

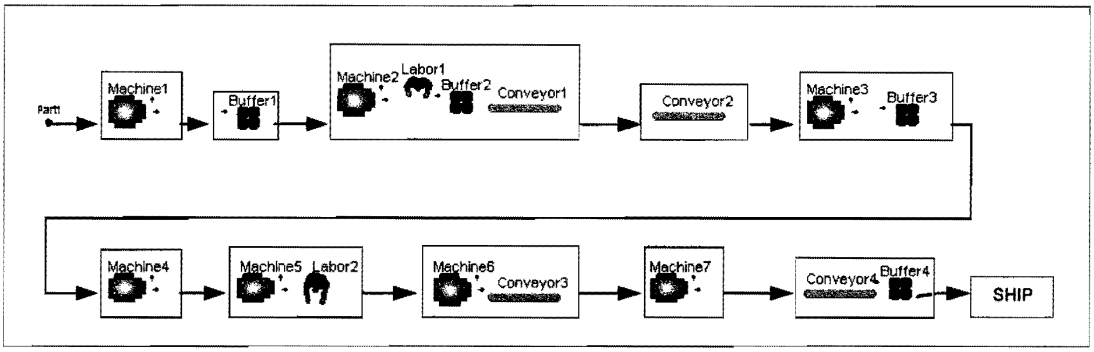


Figure 2: The Amended Model

Note to User: *In order to create the working model shown in figure 2, some of the previous inputs and outputs used in figure 1 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 2	1		2		3		4	✓	5	

Exercise 3: Altering the part route

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 3 below. Link all the elements (Inputs and outputs) as before and run the model when completed.

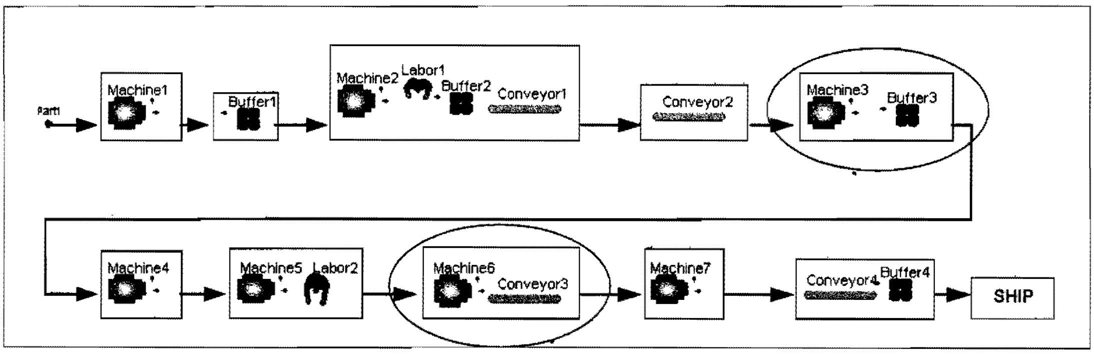


Figure 3: Bypassed elements

Note to User: *In order to create the working model shown in figure 3, some of the previous inputs and outputs used in figure 2 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 3	1		2		3		4	✓	5	

Exercise 4: Key Performance Indicators

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

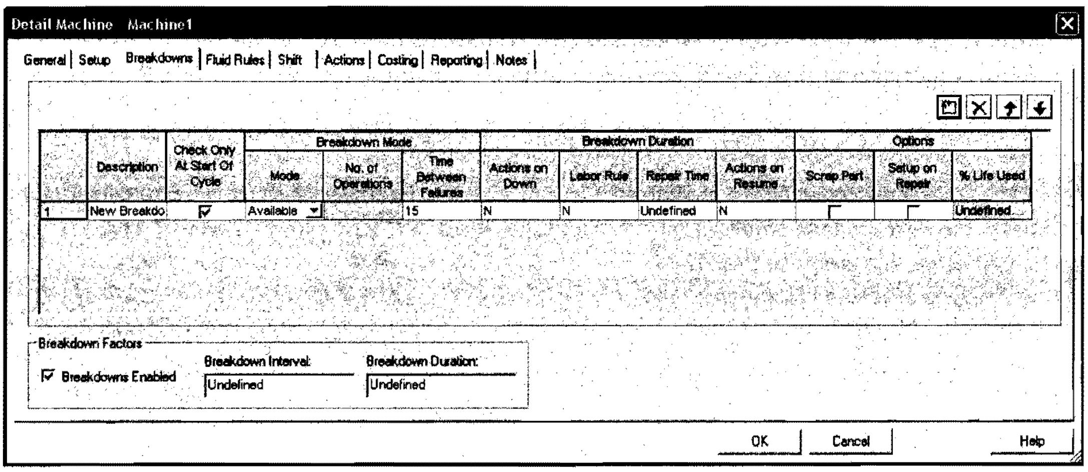


Figure 4: Detailing the Machine Breakdown

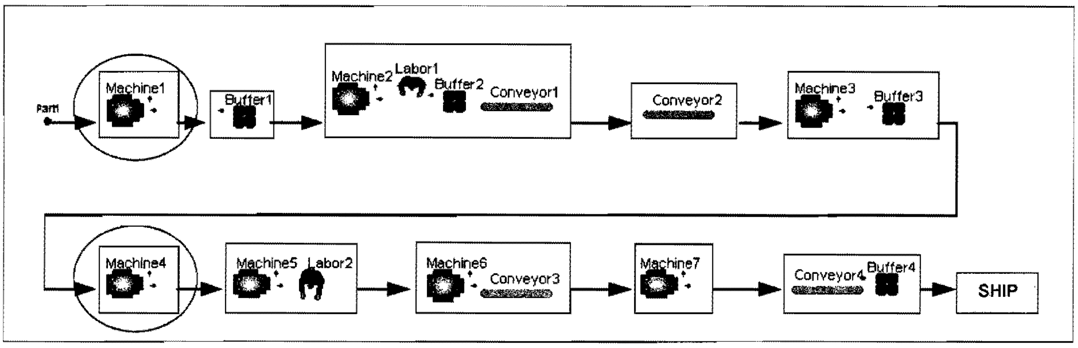


Figure 5: Model with machine breakdowns

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 4" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 4". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	76.	716.
Number of work in progress (WIP)?	24.	716.
The Average Machine Utilisation?	34%.	29%.

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy
Exercise 4a	1		2	X	3		4		5

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 5" as shown in Figure 6 of the model below.

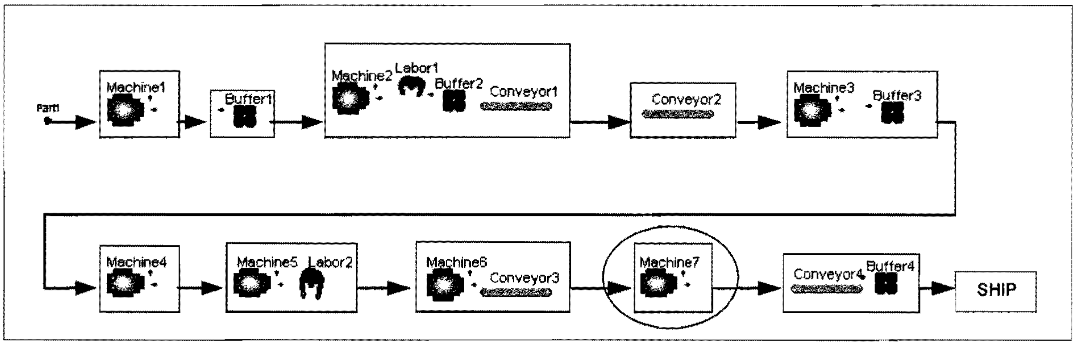


Figure 6: Machine breakdown

The breakdown which occurs in "Machine 5" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 7" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 7" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?	726 .	801 .
Number of work in progress (WIP)?	729 .	811 .
The Average Machine Utilisation?	91%.	96%.

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy
Exercise 4b	1		2		3	X	4		5

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes	X	No	

Time taken to construct the model	29 min 27 sec

Model B: Building the model using the RapidSim Prototype

Using RapidSim:

Step 1:

In order to use the RapidSim Interface you need to open the corresponding Excel File, which in this case is the "ModuleDemo.xlsm". This can be found on the desktop in the folder named "Interface Docs".

Step 2:

Double click on the "ModuleDemo.xlsm" excel file to open it. When opened click on the options button. In the pop up window that opens, select enable this content and then click on OK to proceed.

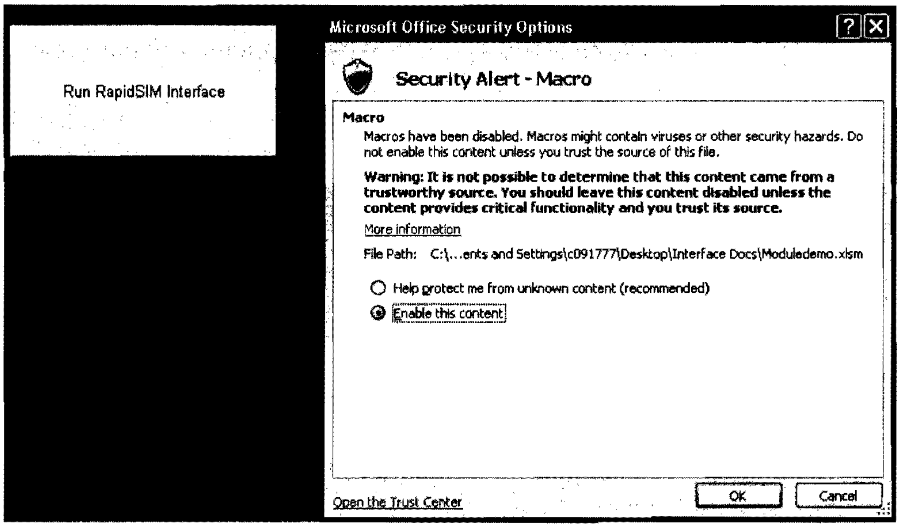


Figure 7: Enabling the system macro's

"Clicking on OK enables the macros's which are programmened in this workbook and it imparts full functionality to the interface".

Step 3

Click on the Run RapidSim Interface button. A new pop up window opens prompting you to select your volume of production. This choice determines which type of manufacturing layout you may most likely be using. Select one of the three options provided, and then click on the next button to proceed with the model building process.

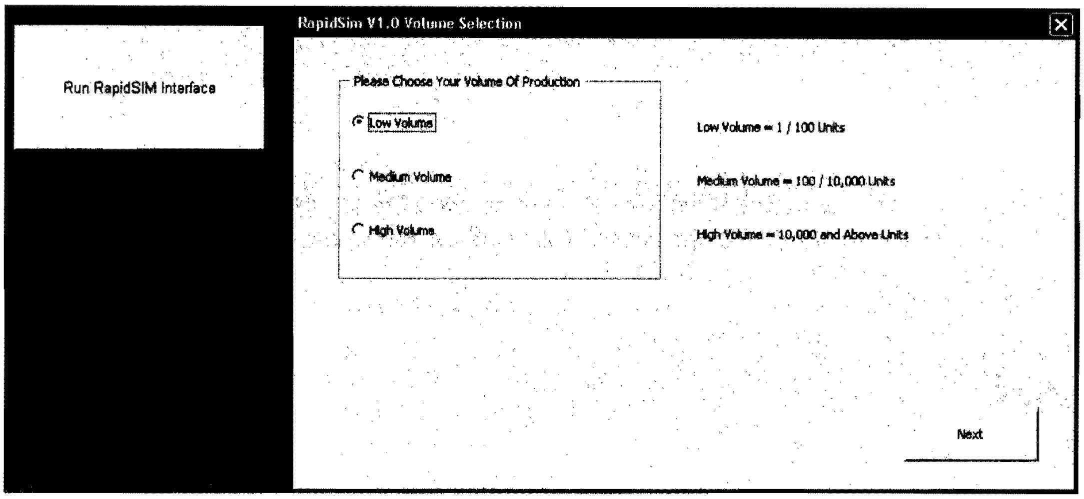


Figure 8: Volume selection

If low volume is selected you will proceed straight to the main interface window. However if medium or high volume Is chosen you will proceed to the System Selection and the Production type selection windows respectively. Clicking on the next button in either of these two frames will take you to the main modeling window.

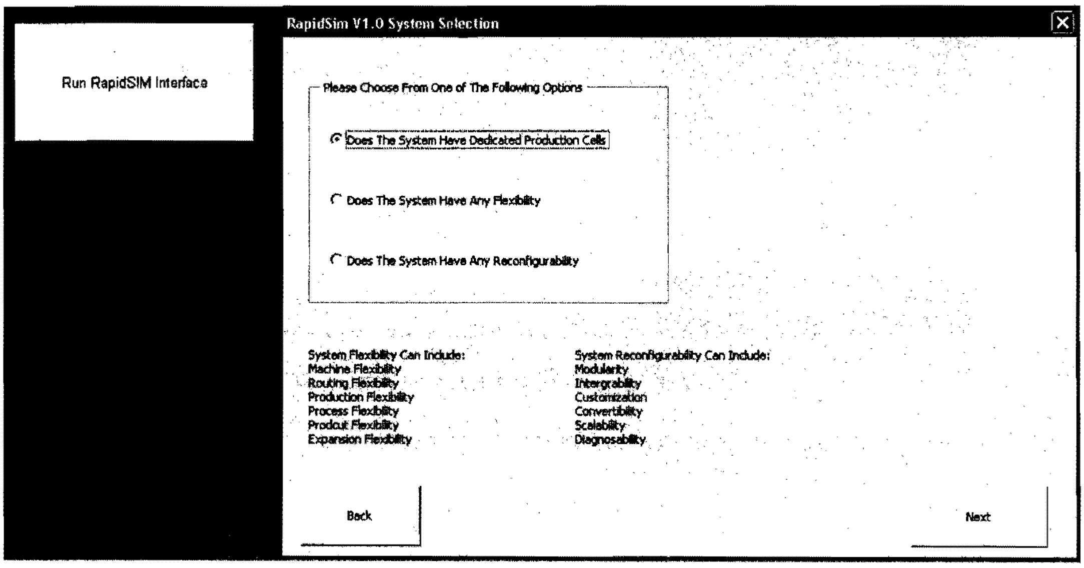


Figure 9: The System selection window

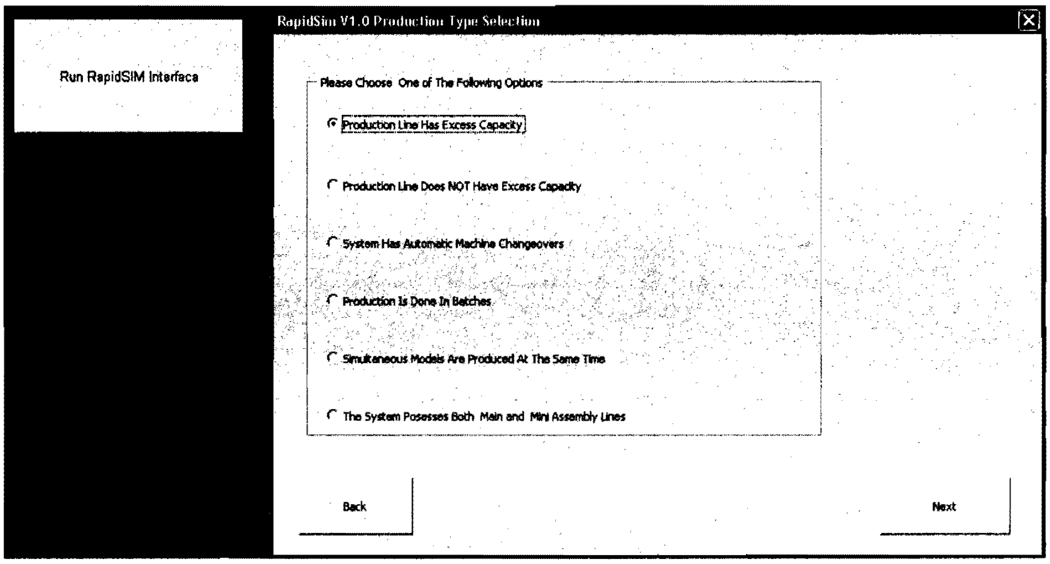


Figure 10: The Production type selection window

Step 4: The Main Interface .

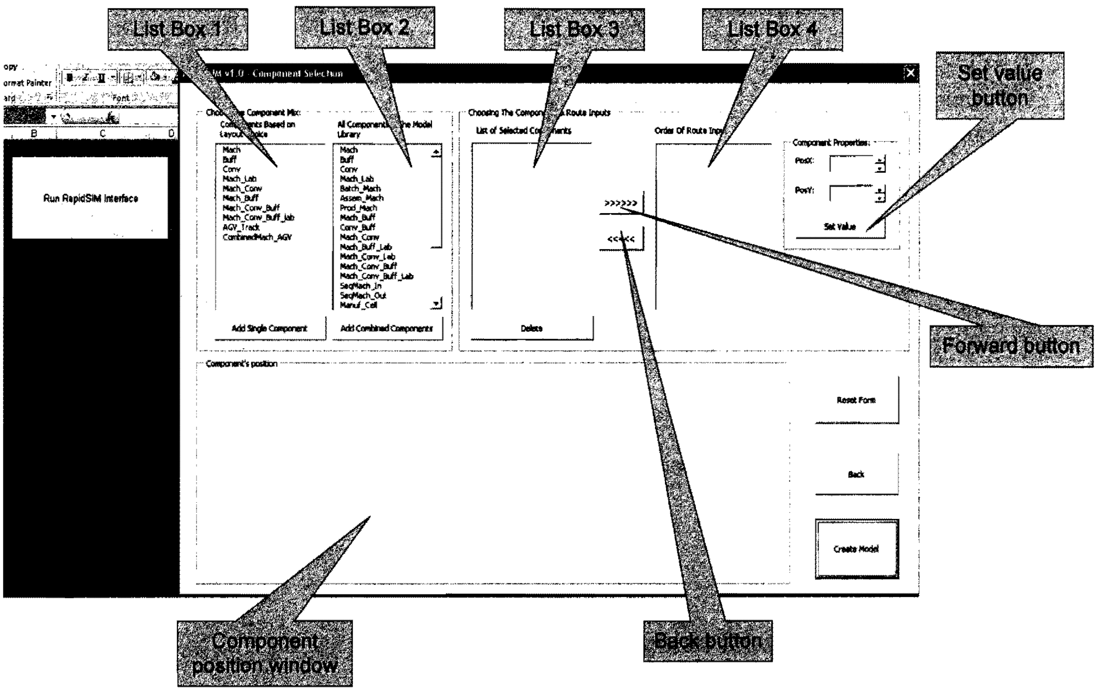


Figure 11: The main interface window

Exercise 1: Build, link and run the simulation model.

Please build the simulation model detailed in figure 7 below using the RapidSim Interface. Link all the elements (Inputs and outputs) and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

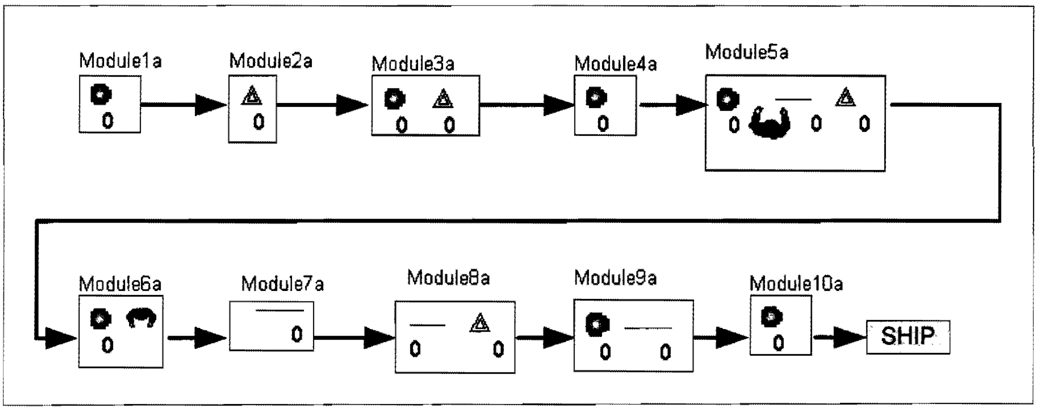


Figure 12: The RapidSim Model

The information presented in Table 2 shows the component and model requirements for the simulation model constructed in Figure 12.

Table 2: Component and Model requirements

Component	**Function**	**Model Requirement**
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

Note to User: *As the shipping machine is added automatically when the model is created it is not necessary for you to specify this machine in the model.*

To construct the model using RapidSim:

- Open the Excel file containing the RapidSim interface
- Enable the workbook macros

- Select the volume of production
- Select the modules then click the add component / add combined component button. Repeat this step to add as many modules as needed
- Select the order of route inputs
- Set the module position using the X & Y co-ordinate system
- Click on create model

Table 3 below details what modules are needed and the quantities required in order to build the model shown in figure 12

Table 3: Module and quantity requirement

Module Needed	**Quantity**
Machine (Mach)	3
Buffer (Buff)	1
Conveyor (Conv)	1
Machine & Buffer (Mach_Buff)	1
Machine & Conveyor (Mach_Conv)	1
Machine & Labor (Mach_Lab)	1
Conveyor & Buffer (Conv_Buff)	1
Machine & Conveyor & Buffer & Labor (Mach_Conv_Buff_Lab)	1

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 1	1	2	3	4 X	5

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly rearrange the modules in the layout to represents the model shown in figure 13 below. The component and model requirements for this exercise remain the same as in exercise 1.

Note to User: *This can be done by altering the order of route inputs and then setting the X & Y co-ordinates.*

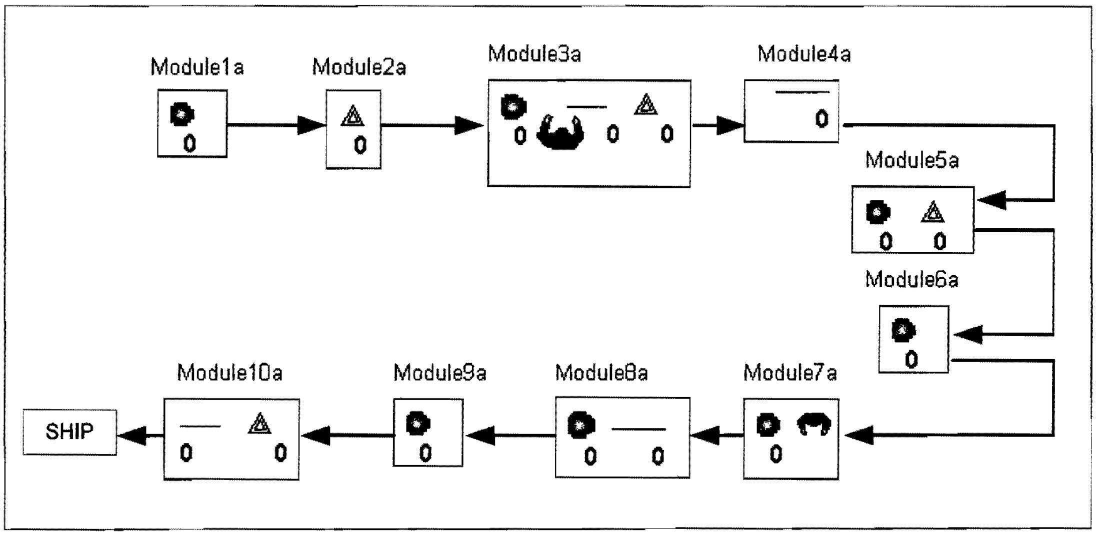


Figure 13: The re-arranged model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise ~~4~~ 2	1	2	3	4	5 X

Exercise 3: Altering the route & model shape

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 14 below. Run the model when completed using the parameters set aside in table 2.

<u>Note to User:</u> *This can be done by deleting the unwanted modules and then setting the X & Y co-ordinates.*

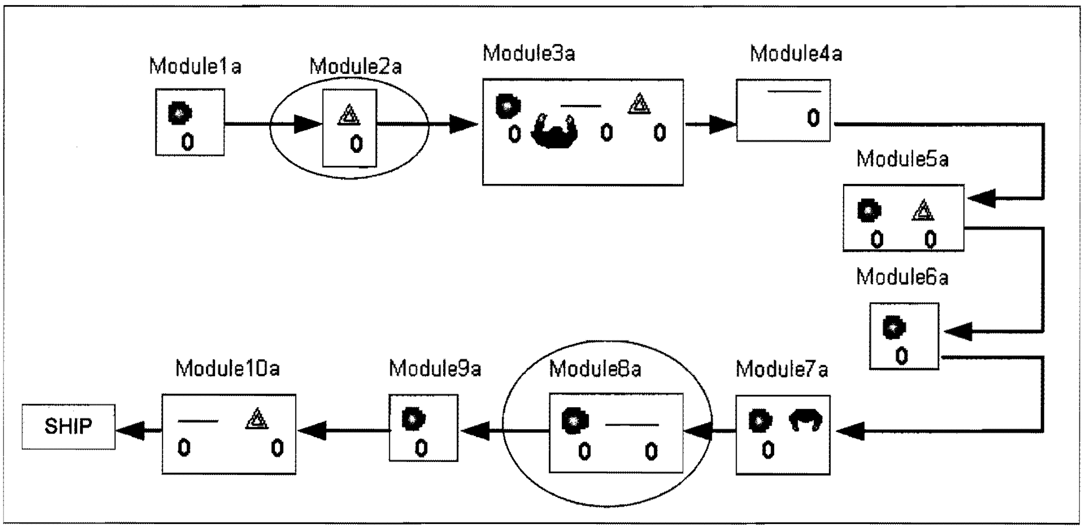


Figure 14: The re-routed model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy	
Exercise ~~4b~~ 3.	1		2		3		4		5	✓

Exercise 4: Key Performance Indicators

General guidelines:

To measure the lead time:

- On the witness demo screen right click on the graph titled "Time_In_Model_Graph" and scroll to and select "statistics". This will display the lead time.

To measure the work in progress (WIP):

- On the witness demo screen right click on the graph titled "WorkInProgress" and scroll to and select "statistics". This will display the WIP. *Alternatively you can read from the WIP value located at the top left hand corner if only a value is required and not an average.*

To measure the Input Buffer Size:

- On the witness demo screen right click on the graph titled "InputBuffer_Size" and scroll to and select "statistics". This will display the lead time.

To count the number of Parts Into the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsIn".

To count the number of Parts out of the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsOut".

To measure the machine utilization:

- Double click on the pie chart in the witness modelling screen (moduledemo.mod)
- Change the refresh interval to 10 unit time then click on the element states tab
- Check the display element state box then select the component to be measured from the drop down list by double clicking on it
- Click on the general tab and delete numbers 4, 6, 7 and 8 from the sectors list then click on ok.
- If the machine utilization for more than one component needs to be measured, simply right click on Pie001 in the model window and select clone. Move the cursor to the witness screen and click. This creates a new pie chart called Pie002 and so on. Follow the steps above to measure the utilization for the component/components.

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

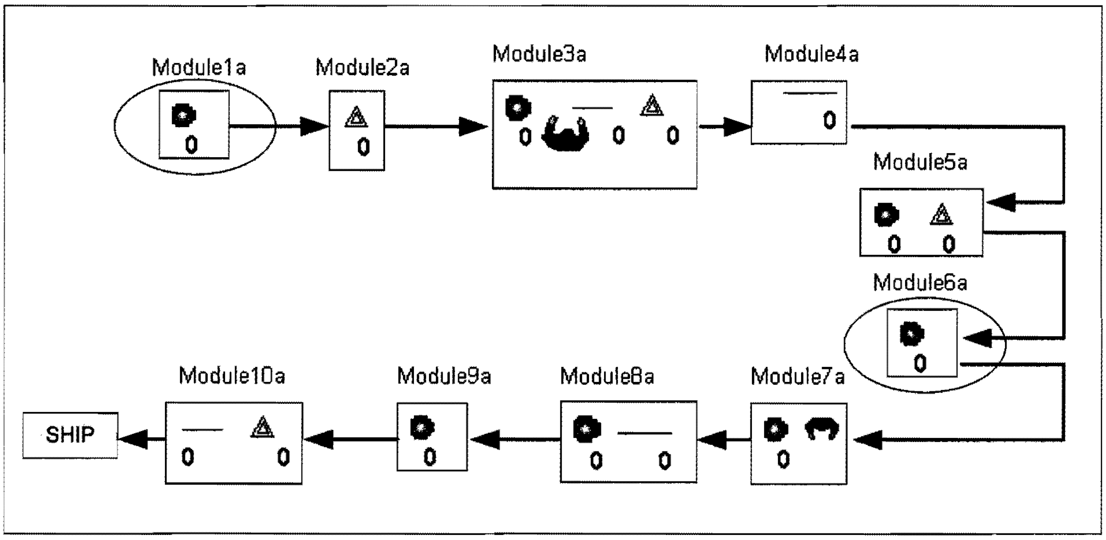


Figure 15: The breakdown model

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 6" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 6". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	676.	688.
Number of work in progress (WIP)?	679.	697.
The Average Machine Utilisation?	34%.	31%

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 9" as shown in Figure 6 of the model below.

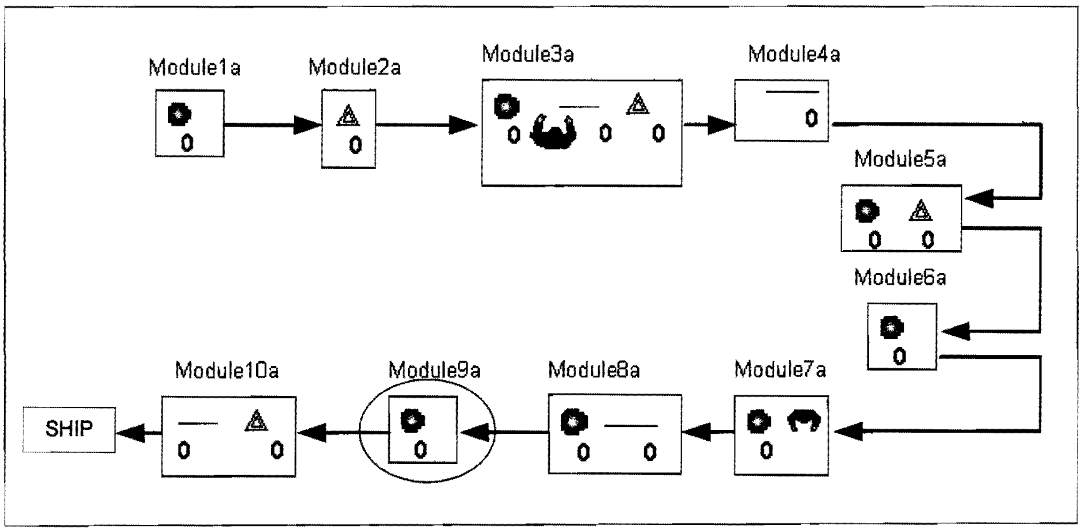


Figure 16: Machine breakdown

The breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 9" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?	698	783
Number of work in progress (WIP)?	705	784
The Average Machine Utilisation?	30%.	21.8

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4b	1		2		3		4		5	X

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes	✓	No	

Time taken to construct the model	12 min 46 sec

If you are confident with the use of the prototype, try building the more complicated model shown in figure 17 of a complex manufacturing system.

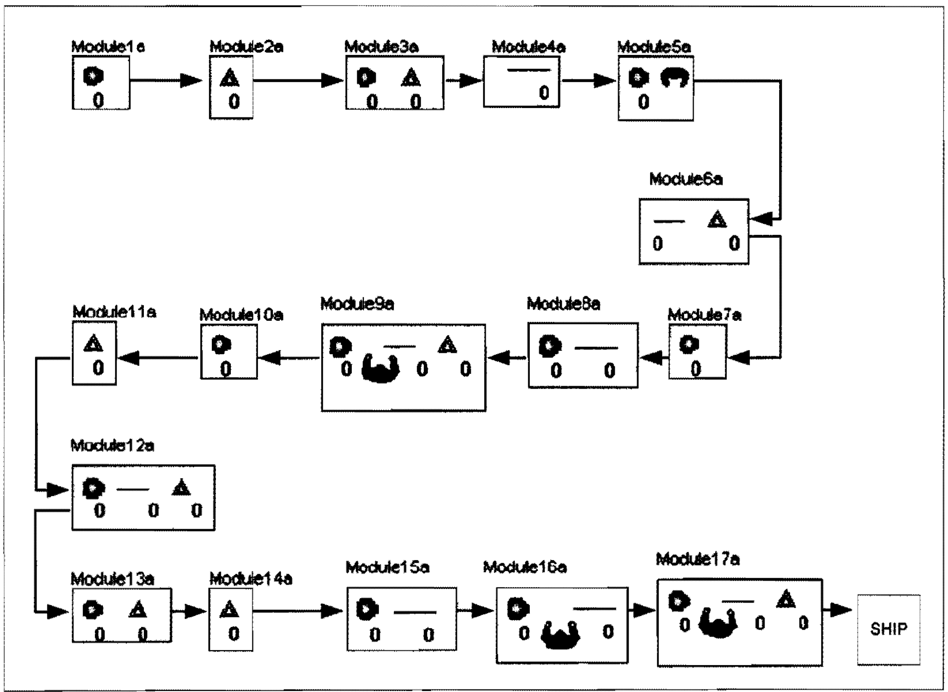


Figure 17: The complicated model

User Feedback:

This following questions put forward in this section of the validation process are to measure to what extent the prototype can help users in the model building process. Please tick the box numbered between 1 – 5 depending on the relevant judging criteria's given.

1. Experience of using Witness Simulation (please tick)

How long have you been involved in the area of simulation and model building?

[redacted]		[redacted]		[redacted]	✓	[redacted]	

2. Usage of Witness software (please tick)

During Lectures Only	X
During group projects	
During thesis project	
Before coming to Cranfield University	

3. Usability

How easy / difficult is it to follow instructions in using the prototype?	1		2		3	~~X~~	4	X	5	
How easy / difficult is it to navigate around the interface?	1		2		3		4	X	5	
How easy / difficult is it to use the prototype?	1		2		3	X	4		5	

4. Speed

How slow / fast is it to construct a model using the prototype?	1		2		3	~~X~~	4	X	5	
How quickly can changes be made to the model?	1		2		3		4	X	5	

5. Performance

How easy / difficult is it to measure the key performance indicators using the prototype?	1		2		3		4		5	X
Are the tools provided to measure the performance indicators useful?	1		2		3		4	X	5	

6. Flexibility

How easy / difficult is it to create components / modules?	1		2		3		4		5	X
How easy / difficult is it to rearrange the physical layout of a model using the prototype?	1		2		3		4		5	X
How easy / difficult is it to alter the physical routing of parts using the prototype?	1		2		3		4	X	5	
How easy / difficult is it to bypass elements in a layout using the prototype?	1		2		3		4	X	5	
How easy / difficult is it to model "breakdowns" using the prototype	1		2		3		4		5	X
How easy / difficult is it to link components and run the model using the prototype?	1		2		3		4	X	5	
How flexible is modelling with the prototype compared to building models manually?	1		2		3		4		5	X

7. Usefulness

The prototype will help in the model building process	1		2		3		4	X	5	
The prototype will help reduce the overall model building time	1		2		3		4		5	X
Using the prototype allows me to create physical components easier and faster.	1		2		3		4	X	5	
Linking and running the modules / components can be done easily and effictively	1		2		3		4	X	5	
Switching any element On / Off and re-linking the model can be done easily	1		2		3		4	X	5	
The prototype has potential for improving the model building process	1		2		3		4		5	X

8. Comments / suggestions

ABDULLAH ALABDULKARIM.

Model A: Building a Manual Simulation Model

Exercise 1: Build, link and run the simulation model.

Please build the simulation model as detailed in figure 1 below. Link all the elements (Inputs and outputs) using "Push" and "Pull" rules and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

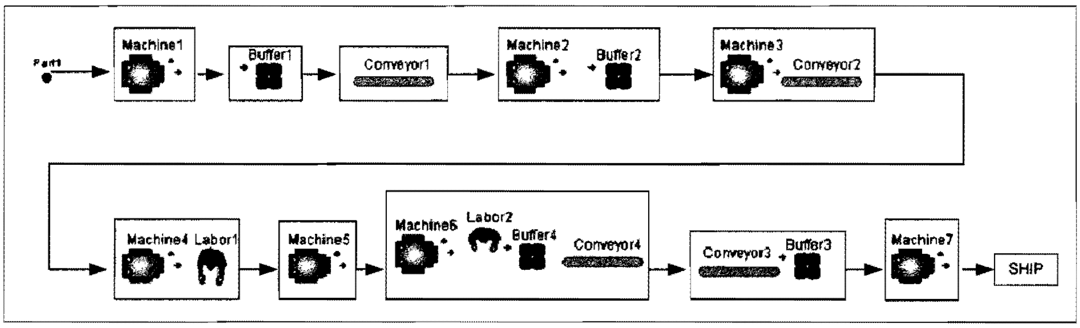


Figure 1: The Manual Model

The information presented in Table 1 shows the component and model requirements for the simulation model constructed in Figure 1.

Table 1: Component and Model requirements

Component	**Function**	**Model Requirement**
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 1	1	2	3	4	5

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly alter the position of the components in the layout to represents the model shown in figure 2 below. Link all the elements (Inputs and outputs) as before and run the model when completed. The component and model requirements for this exercise remain the same as in exercise 1.

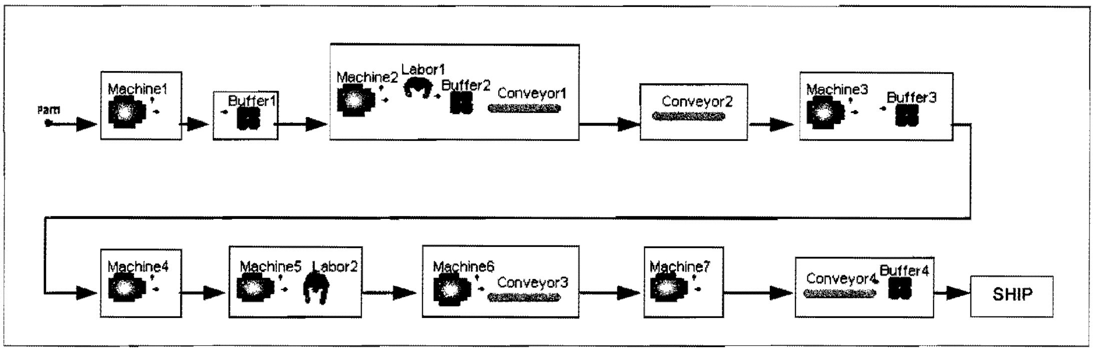


Figure 2: The Amended Model

<u>Note to User:</u> *In order to create the working model shown in figure 2, some of the previous inputs and outputs used in figure 1 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 2	1	2	✓ 3	4	5

Exercise 3: Altering the part route

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 3 below. Link all the elements (Inputs and outputs) as before and run the model when completed.

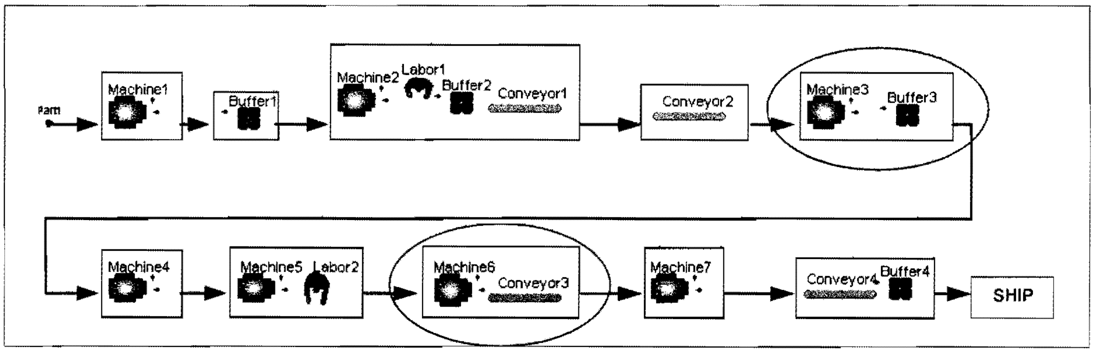


Figure 3: Bypassed elements

<u>Note to User:</u> *In order to create the working model shown in figure 3, some of the previous inputs and outputs used in figure 2 will have to be deleted and then recreated in order for the model to work.*

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 3	1	2	3	✓ 4	5

Exercise 4: Key Performance Indicators

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

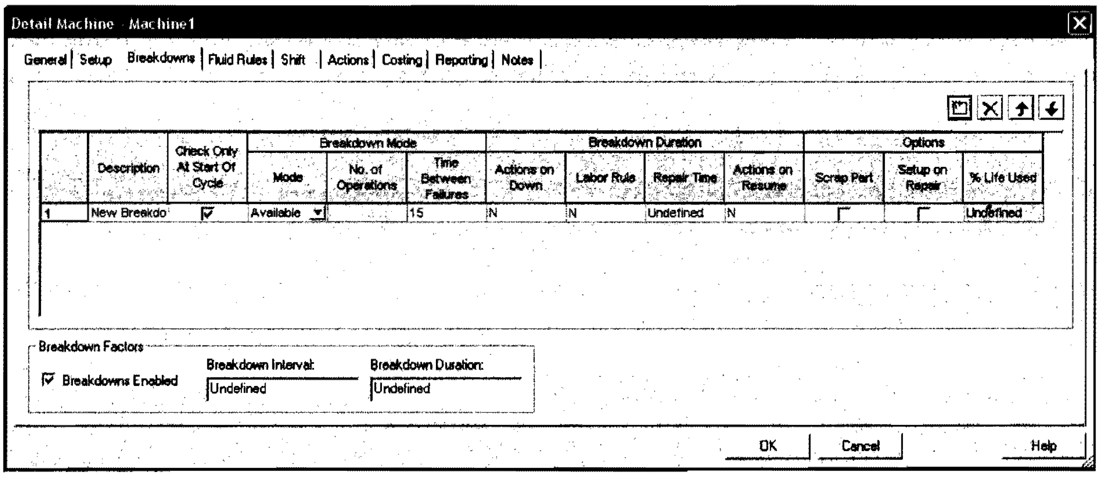


Figure 4: Detailing the Machine Breakdown

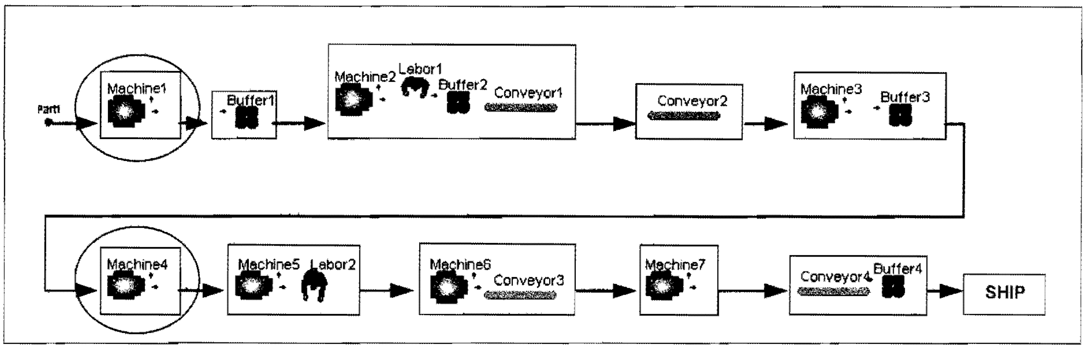


Figure 5: Model with machine breakdowns

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 4" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 4". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?		
Number of work in progress (WIP)?		
The Average Machine Utilisation?		

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult								Easy
Exercise 4a	1		2	✓	3		4		5

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 5" as shown in Figure 6 of the model below.

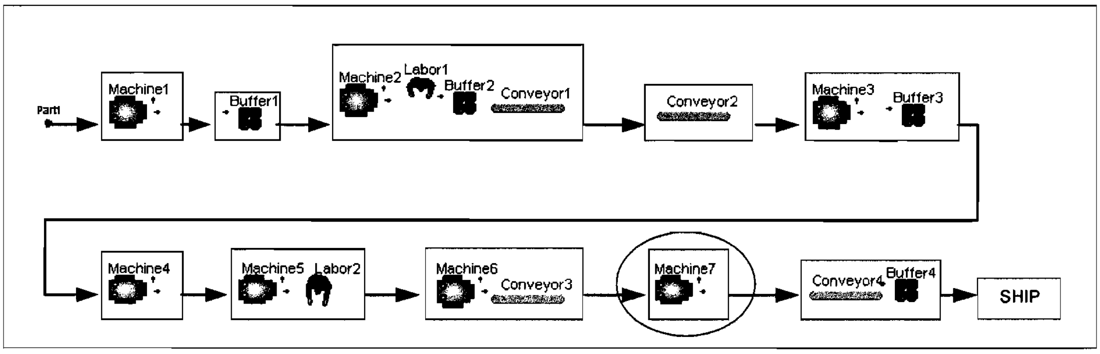


Figure 6: Machine breakdown

The breakdown which occurs in "Machine 5" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 7" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 7" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 7" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 7". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?		
Number of work in progress (WIP)?	Unable to	complete.
The Average Machine Utilisation?		

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4b	1		2	✓	3		4		5	

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes		No	✓

Time taken to construct the model	33.27 mins.

Model B: Building the model using the RapidSim Prototype

Using RapidSim:

Step 1:

In order to use the RapidSim Interface you need to open the corresponding Excel File, which in this case is the "ModuleDemo.xlsm". This can be found on the desktop in the folder named "Interface Docs".

Step 2:

Double click on the "ModuleDemo.xlsm" excel file to open it. When opened click on the options button. In the pop up window that opens, select enable this content and then click on OK to proceed.

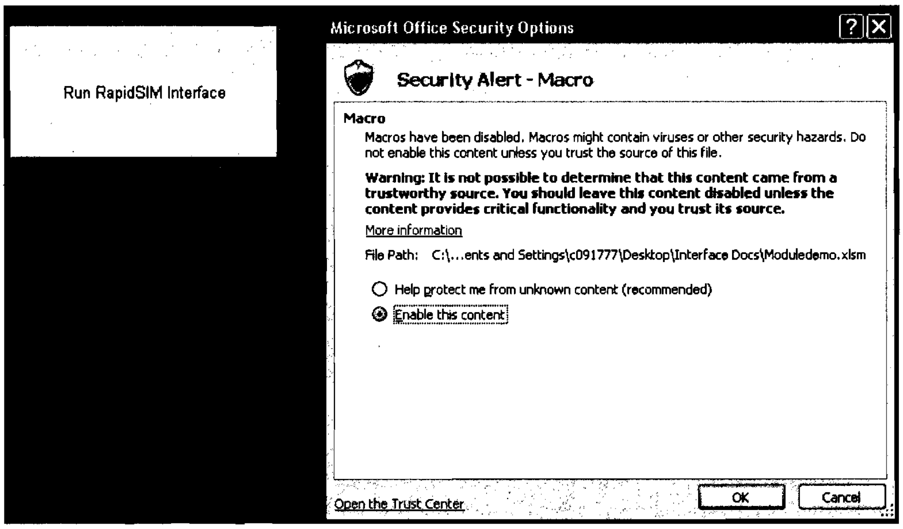


Figure 7: Enabling the system macro's

"Clicking on OK enables the macros's which are programmened in this workbook and it imparts full functionality to the interface".

Step 3

Click on the Run RapidSim Interface button. A new pop up window opens prompting you to select your volume of production. This choice determines which type of manufacturing layout you may most likely be using. Select one of the three options provided, and then click on the next button to proceed with the model building process.

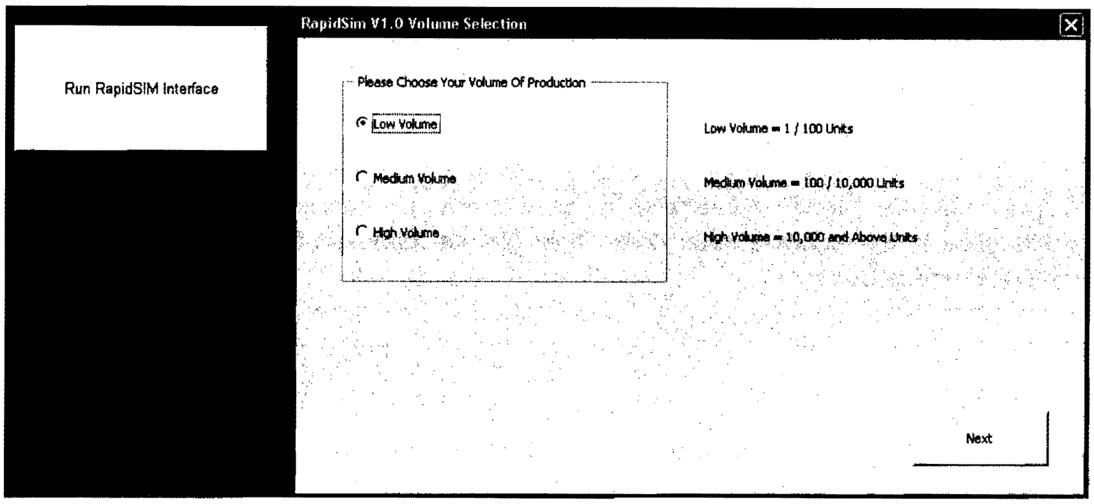


Figure 8: Volume selection

If low volume is selected you will proceed straight to the main interface window. However if medium or high volume Is chosen you will proceed to the System Selection and the Production type selection windows respectively. Clicking on the next button in either of these two frames will take you to the main modeling window.

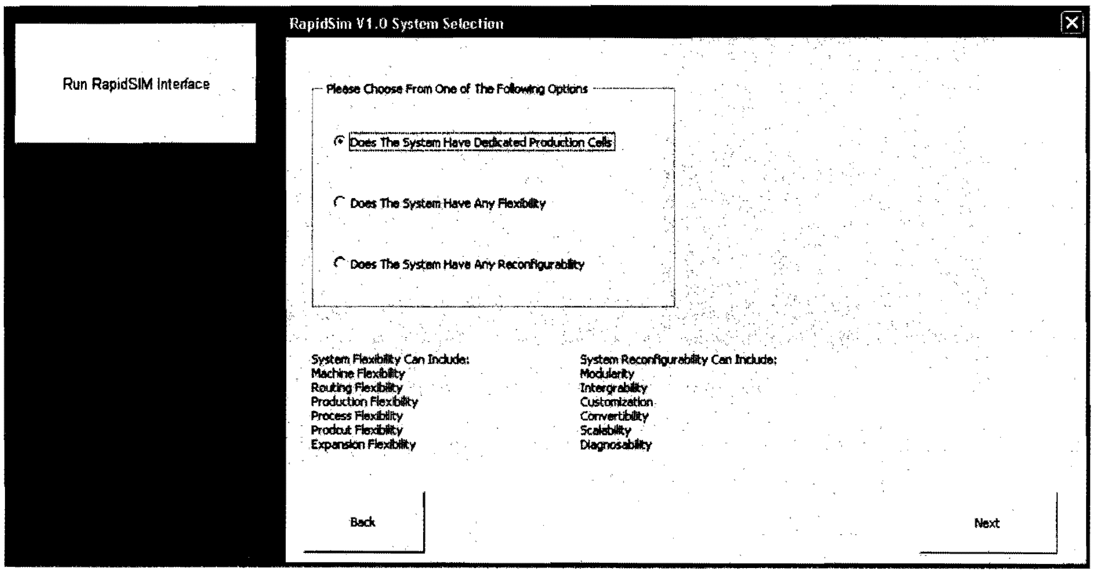


Figure 9: The System selection window

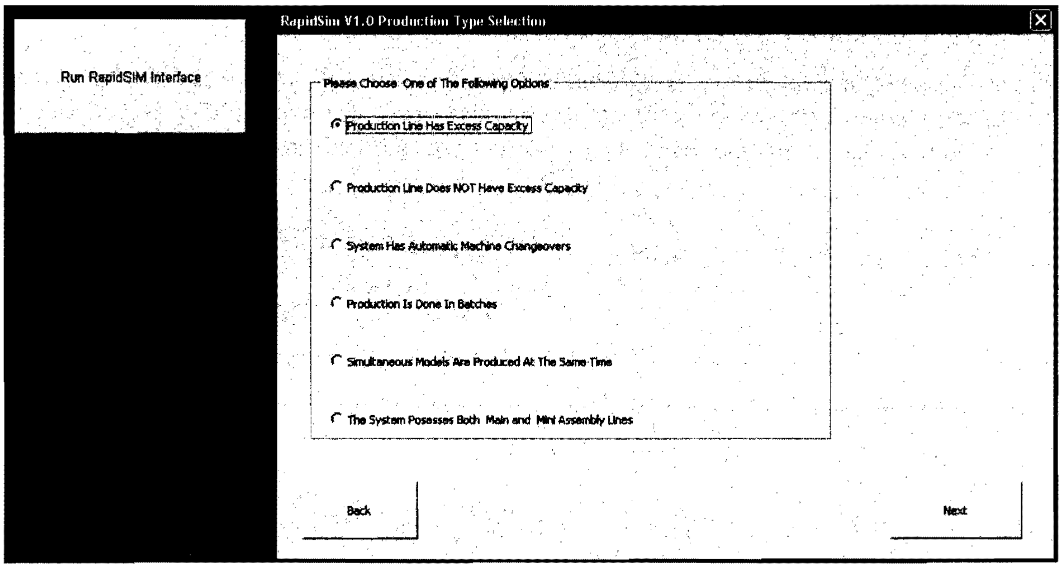


Figure 10: The Production type selection window

Step 4: The Main Interface .

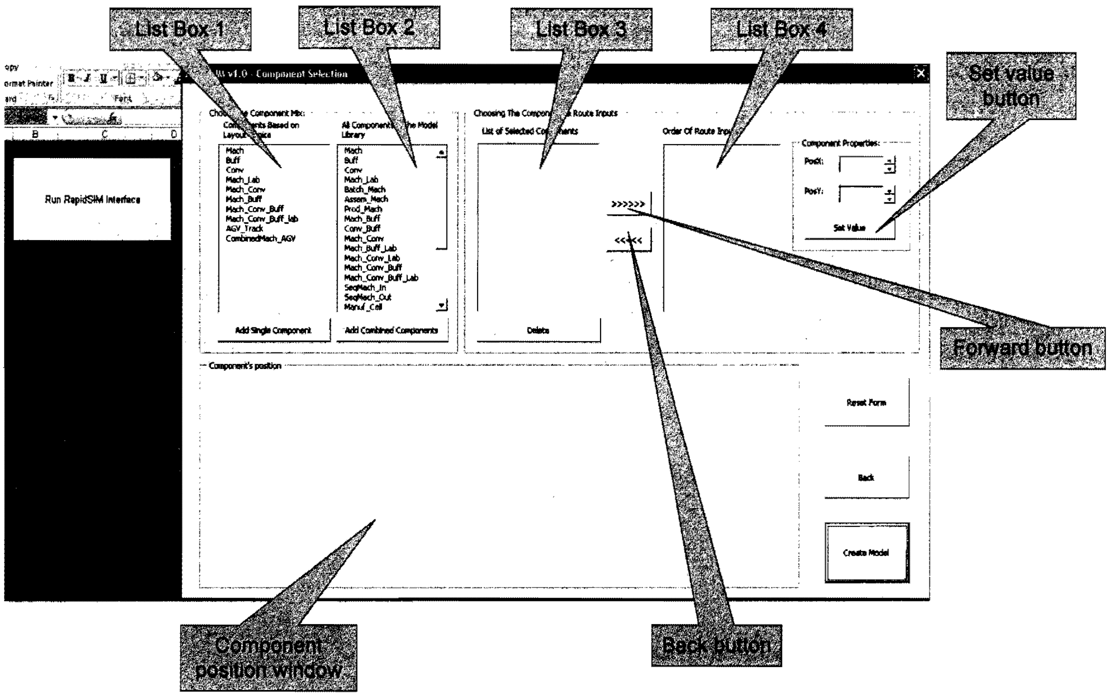


Figure 11: The main interface window

Exercise 1: Build, link and run the simulation model.

Please build the simulation model detailed in figure 7 below using the RapidSim Interface. Link all the elements (Inputs and outputs) and run the model when completed. A part enters Machine 1 and then progresses to all the subsequent components shown below.

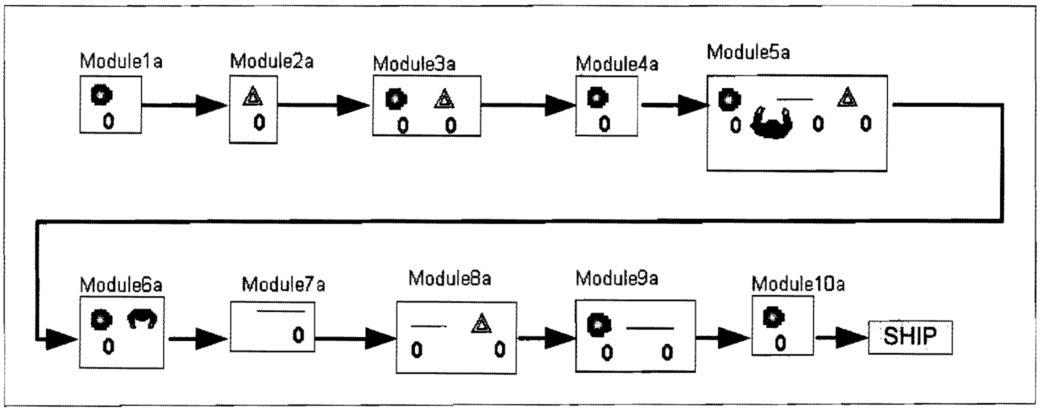


Figure 12: The RapidSim Model

The information presented in Table 2 shows the component and model requirements for the simulation model constructed in Figure 12.

Table 2: Component and Model requirements

Component	Function	Model Requirement
Part (Active)	Delivery	1 every 1 unit time
All machines (Single type)	Machine cycle times	1.0 unit time
All buffers	Buffer capacity	Default value (1000)
All conveyors	Maximum capacity	20
	Length in parts	20
	Conveyor type	Index queuing (Default)
	Index time	0.5
Labor	Adds labor to a machine	Always available
Completed model	Run time	1000 unit time

Note to User: *As the shipping machine is added automatically when the model is created it is not necessary for you to specify this machine in the model.*

To construct the model using RapidSim:

- Open the Excel file containing the RapidSim interface
- Enable the workbook macros

- Select the volume of production
- Select the modules then click the add component / add combined component button. Repeat this step to add as many modules as needed
- Select the order of route inputs
- Set the module position using the X & Y co-ordinate system
- Click on create model

Table 3 below details what modules are needed and the quantities required in order to build the model shown in figure 12

Table 3: Module and quantity requirement

Module Needed	**Quantity**
Machine (Mach)	3
Buffer (Buff)	1
Conveyor (Conv)	1
Machine & Buffer (Mach_Buff)	1
Machine & Conveyor (Mach_Conv)	1
Machine & Labor (Mach_Lab)	1
Conveyor & Buffer (Conv_Buff)	1
Machine & Conveyor & Buffer & Labor (Mach_Conv_Buff_Lab)	1

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy	
Exercise 1	1	2	3	4	5	✓

Exercise 2: Rearranging the model

Using the model constructed in exercise 1, kindly rearrange the modules in the layout to represents the model shown in figure 13 below. The component and model requirements for this exercise remain the same as in exercise 1.

<u>Note to User:</u> *This can be done by altering the order of route inputs and then setting the X & Y co-ordinates.*

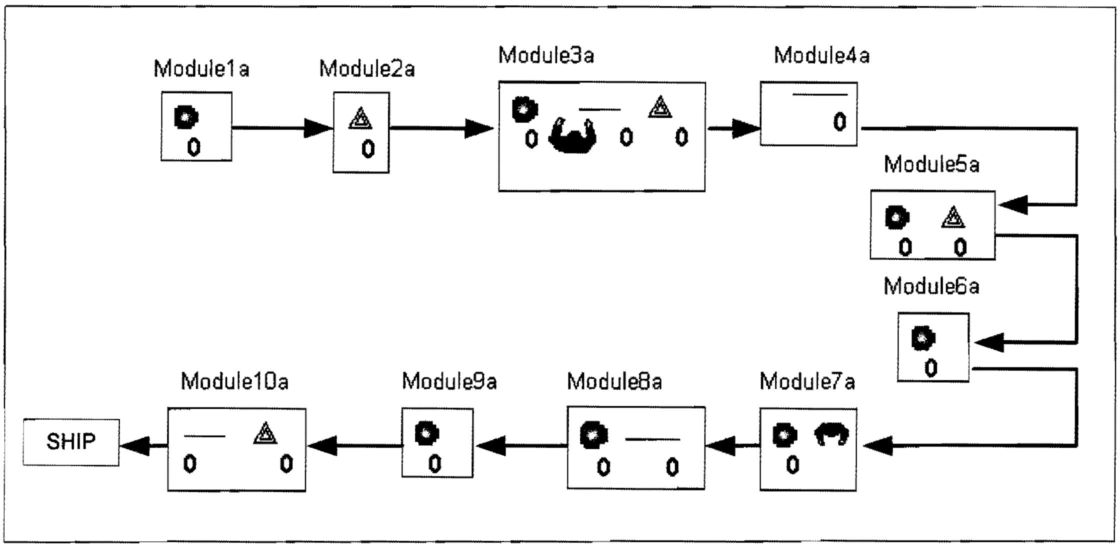


Figure 13: The re-arranged model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise 2	1	2	3	4	5 ✓

Exercise 3: Altering the route & model shape

Using the model constructed in exercise 2, kindly alter the route of the part used in the layout to represents the model shown in figure 3 below. The part needs to bypass the circled elements as shown in figure 14 below. Run the model when completed using the parameters set aside in table 2.

<u>**Note to User:**</u> *This can be done by deleting the unwanted modules and then setting the X & Y co-ordinates.*

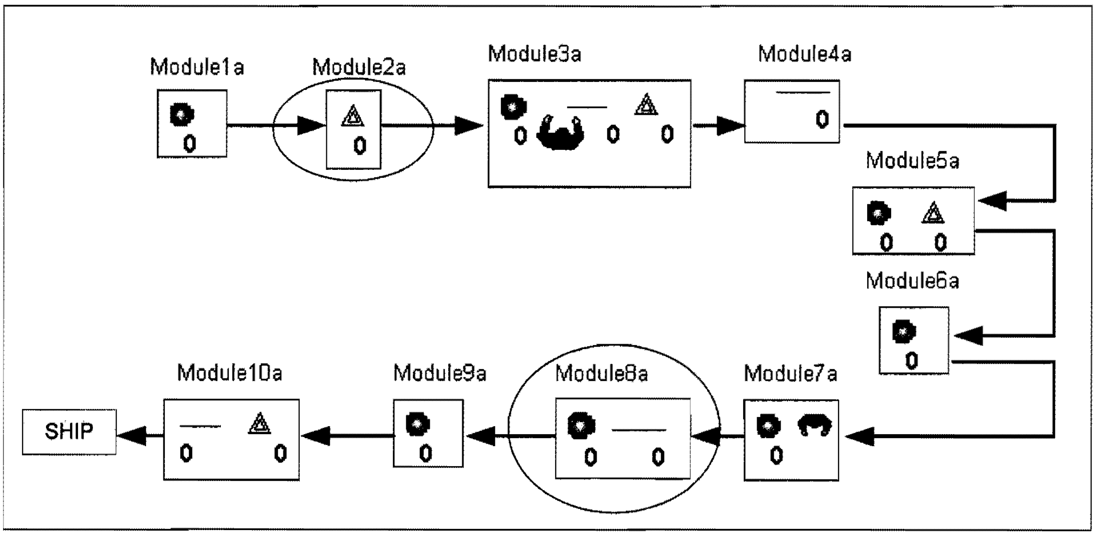


Figure 14: The re-routed model

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult				Easy
Exercise ~~4~~ 3	1	2	3	4	5 ✓

Exercise 4: Key Performance Indicators

General guidelines:

To measure the lead time:

- On the witness demo screen right click on the graph titled "Time_In_Model_Graph" and scroll to and select "statistics". This will display the lead time.

To measure the work in progress (WIP):

- On the witness demo screen right click on the graph titled "WorkInProgress" and scroll to and select "statistics". This will display the WIP. *Alternatively you can read from the WIP value located at the top left hand corner if only a value is required and not an average.*

To measure the Input Buffer Size:

- On the witness demo screen right click on the graph titled "InputBuffer_Size" and scroll to and select "statistics". This will display the lead time.

To count the number of Parts Into the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsIn".

To count the number of Parts out of the system:

- This count value can be read at the top left hand corner of the witness screen, under the variable "PartsOut".

To measure the machine utilization:

- Double click on the pie chart in the witness modelling screen (moduledemo.mod)
- Change the refresh interval to 10 unit time then click on the element states tab
- Check the display element state box then select the component to be measured from the drop down list by double clicking on it
- Click on the general tab and delete numbers 4, 6, 7 and 8 from the sectors list then click on ok.
- If the machine utilization for more than one component needs to be measured, simply right click on Pie001 in the model window and select clone. Move the cursor to the witness screen and click. This creates a new pie chart called Pie002 and so on. Follow the steps above to measure the utilization for the component/components.

Compare the effects of machine breakdown against the lead time, work in progress (WIP) and machine utilisation at the beginning and towards the end of the model shown above.

Exercise 4a (i)

- In order to include a breakdown in "Machine 1" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 below.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 1". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

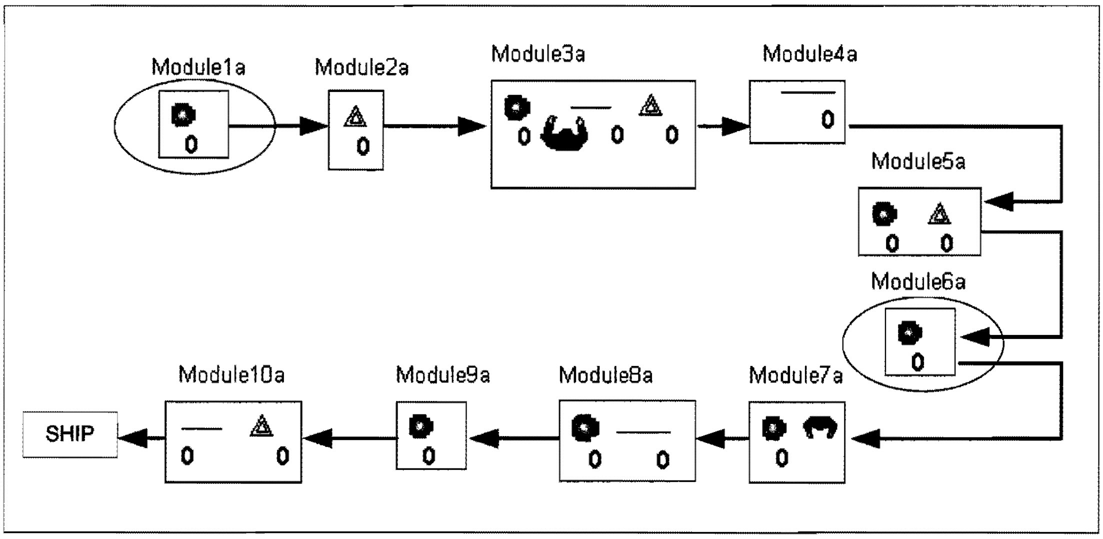


Figure 15: The breakdown model

Exercise 4a (ii)

- Delete the breakdown imposed on "Machine 1"
- In order to include a breakdown in "Machine 6" It is necessary to specify that the breakdown will occur in the element as shown in figure 4 above.
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 6". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4a (i)	Exercise 4a (ii)
What is the average lead time?	48.1	678.1
Number of work in progress (WIP)?	48	678
The Average Machine Utilisation?	100%	33.7.

Exercise 4b (i)

Compare the effects of machine breakdown for "Machine 9" as shown in Figure 6 of the model below.

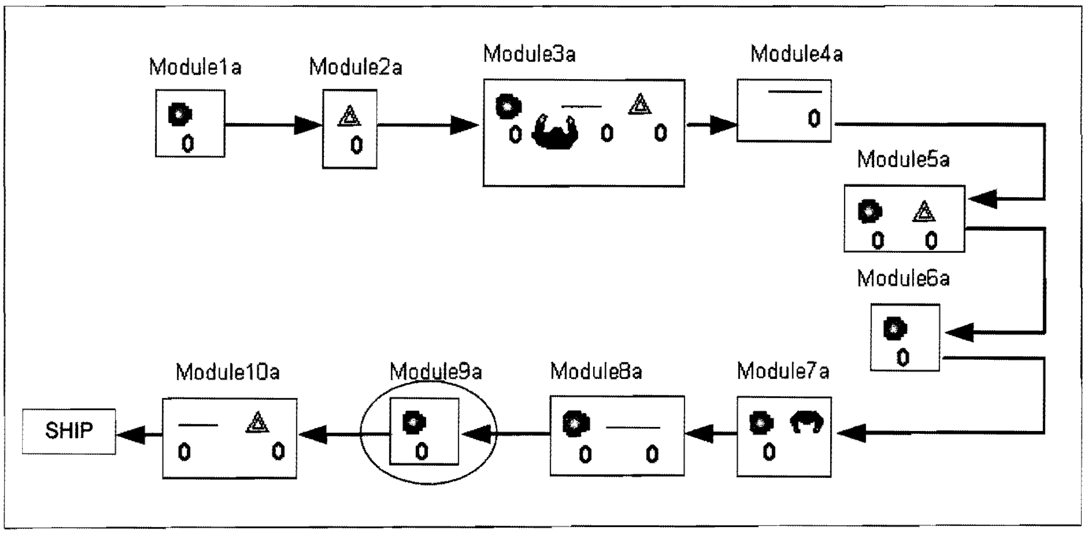


Figure 16: Machine breakdown

The breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 15 unit time
Repair Time (RT)	1 every 10 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Exercise 4b (ii)

Delete the breakdown previously imposed on "Machine 9" and insert a new breakdown condition.

The new breakdown which occurs in "Machine 9" must contain the following information relating to the Mean Time Between Failure (MTBF) and the Repair Time (RT).

Condition	Requirement
Mean Time Between Failure (MTBF)	1 every 20 unit time
Repair Time (RT)	1 every 15 unit time

- In order to include a breakdown in "Machine 9" It is necessary to specify that the breakdown will occur in the element
- Find the average lead time for the model (Please use a histogram to display the average lead time)
- Find the number of work in progress (WIP) (Please use a time series graph to plot the number of WIP over the given time)
- Find the average machine utilisation of "Machine 9". (Please use a pie chart to display the waiting time percentage, the busy time percentage, the blocked time percentage and the broken down percentage of the machine).

Compare how the two breakdown conditions imposed on the model above, affects the lead time, the Work in progress (WIP) and the machine utilisation.

Key Performance Indicators	Exercise 4b (i)	Exercise 4b (ii)
What is the average lead time?	698.1	783.1
Number of work in progress (WIP)?	698	783
The Average Machine Utilisation?	30.1	24.8

On a Scale of 1 to 5 kindly choose the level of difficulty of the above completed exercise by ticking the relevant box.

Exercise No:	Difficult									Easy
Exercise 4b	1		2		3		4		5	✓

Were you able to complete the Key Performance Measures outlined in the exercise above?	Yes	✓	No	

Time taken to construct the model	12 minutes.

If you are confident with the use of the prototype, try building the more complicated model shown in figure 17 of a complex manufacturing system.

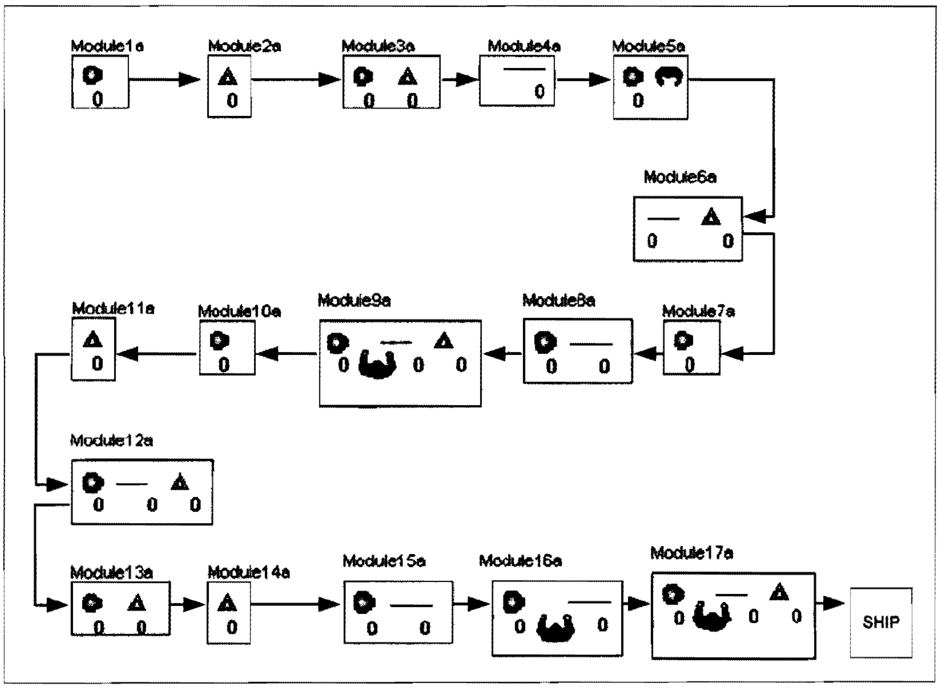


Figure 17: The complicated model

User Feedback:

This following questions put forward in this section of the validation process are to measure to what extent the prototype can help users in the model building process. Please tick the box numbered between 1 – 5 depending on the relevant judging criteria's given.

1. **Experience of using Witness Simulation (please tick)**

How long have you been involved in the area of simulation and model building?

[redacted]

2. **Usage of Witness software (please tick)**

During Lectures Only	
During group projects	
During thesis project	✓
Before coming to Cranfield University	

3. Usability

How easy / difficult is it to follow instructions in using the prototype?	1		2		3		4	✓	5	
How easy / difficult is it to navigate around the interface?	1		2		3		4		5	✓
How easy / difficult is it to use the prototype?	1		2		3		4	✓	5	

4. Speed

How slow / fast is it to construct a model using the prototype?	1		2		3		4	✓	5	
How quickly can changes be made to the model?	1		2		3		4	✓	5	

5. Performance

How easy / difficult is it to measure the key performance indicators using the prototype?	1		2		3		4		5	✓
Are the tools provided to measure the performance indicators useful?	1		2		3		4		5	✓

6. Flexibility

How easy / difficult is it to create components / modules?	1		2		3		4	✓	5	
How easy / difficult is it to rearrange the physical layout of a model using the prototype?	1		2		3		4	✓	5	
How easy / difficult is it to alter the physical routing of parts using the prototype?	1		2		3		4	✓	5	
How easy / difficult is it to bypass elements in a layout using the prototype?	1		2		3		4		5	✓
How easy / difficult is it to model "breakdowns" using the prototype	1		2		3		4		5	✓
How easy / difficult is it to link components and run the model using the prototype?	1		2		3		4	✓	5	
How flexible is modelling with the prototype compared to building models manually?	1		2		3		4		5	✓

7. Usefulness

The prototype will help in the model building process	1	2	3	4	5	✓
The prototype will help reduce the overall model building time	1	2	3	4	5	✓
Using the prototype allows me to create physical components easier and faster.	1	2	3	4	5	✓
Linking and running the modules / components can be done easily and effictively	1	2	3	4 ✓	5	
Switching any element On / Off and re-linking the model can be done easily	1	2	3	4 ✓	5	
The prototype has potential for improving the model building process	1	2	3	4	5	✓

8. Comments / suggestions